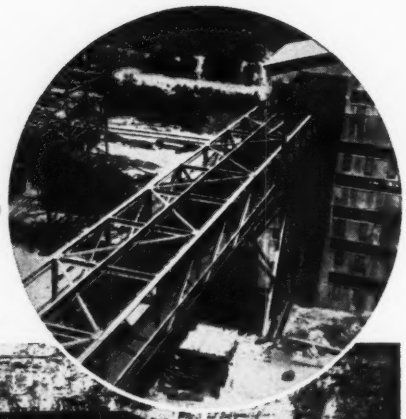
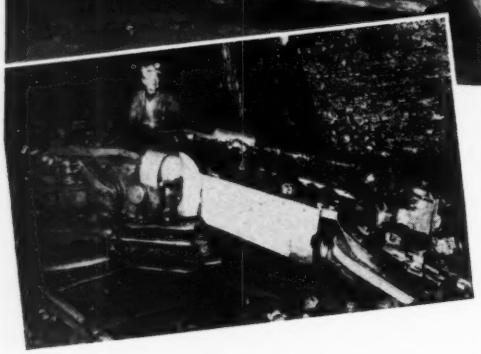
In this issue: COAL MINE LUBRICATION
AUGUST, 1952
Vol. 8, No. 4

Lubrication ENGINEERING

JOURNAL OF
THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

"*Trabon* HAS THE ONLY COMPLETELY ENCLOSED MEASURING VALVE THAT NOTIFIES THE OPERATOR IF TROUBLE DEVELOPS!"





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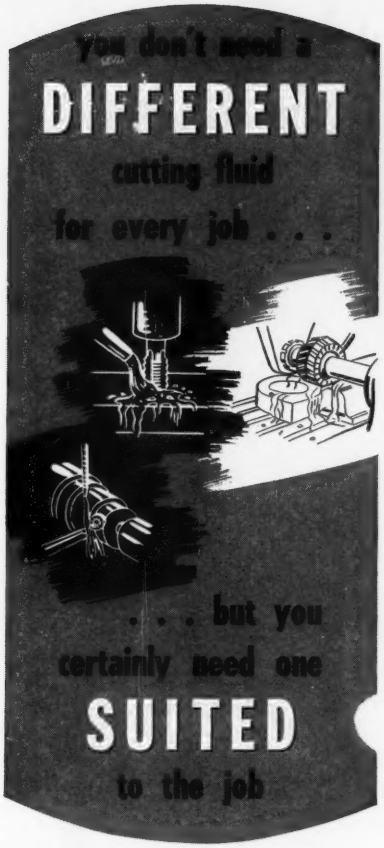
Trabon LUBRICATING SYSTEMS

Many bearings can be handled from a single pumping point by Trabon. The Trabon system handles both oil and grease, and can be buried under coal dust, water, ice, dirt and grime with perfect safety . . . and with assurance that the sealed Trabon system will deliver just the right amount of clean lubricant to each bearing.

Trabon oil and grease systems are rugged, positive, dependable. On conveyors, loaders, crushers, washers, shuttle cars and cones, Trabon lubrication pays for itself through bearing protection, less down time and more production.

TRABON ENGINEERING CORPORATION
1814 EAST 40TH STREET • CLEVELAND 3, OHIO

Trabon
OIL AND GREASE SYSTEMS



THERE is no one cutting fluid that best meets the requirements of every job. Therefore, Stuart offers you a *complete* line of cutting fluids. Often two or three Stuart cutting fluids, or varying dilutions of one or two, will answer all the needs of a shop. But, what a whale of a difference it makes when the cutting fluid that is used is the right one for the job!

GEAR SHAVING TOOL LIFE INCREASED 50%, FINISH IMPROVED WITH STUART'S THREDKUT

In a Chicago plant, two gear shavers were run side by side on the same job, one with the old cutting oil, one with Stuart's THREDKUT. Tool life with "x" oil—6000 gears; with THREDKUT —*9000 gears!* Finish with the other oil—satisfactory until 2500 to 3000 gears had been produced, then deteriorating until tools were replaced; with THREDKUT —completely satisfactory at all times.

It pays to put the *right* cutting fluid on the job. Ask to have a Stuart sales-engineer call.

● ●

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TIME-TESTED

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Lubrication ENGINEERING

AUGUST, 1952, Vol. 8, No. 4

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LUBRICATION ENGINEERING

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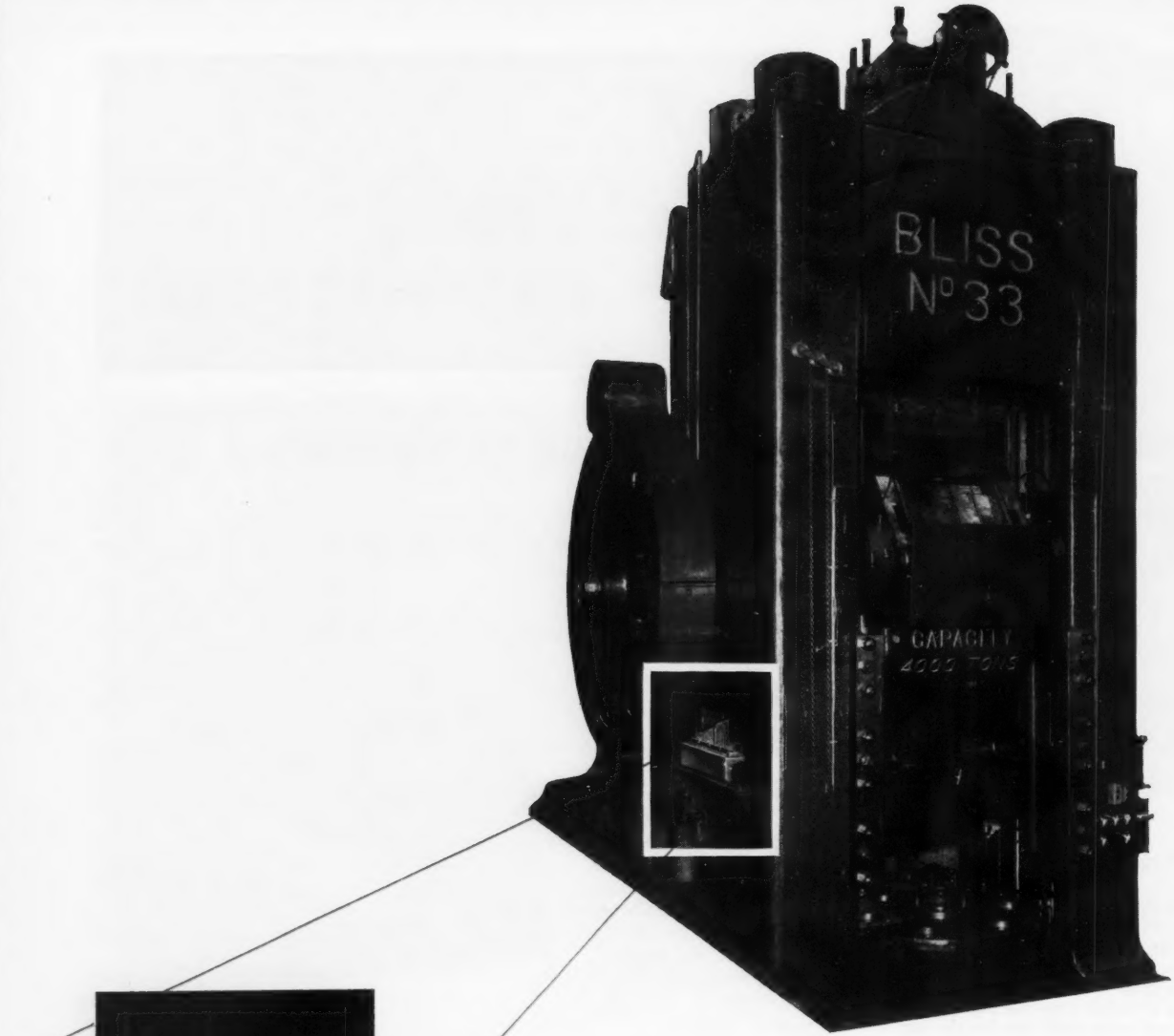

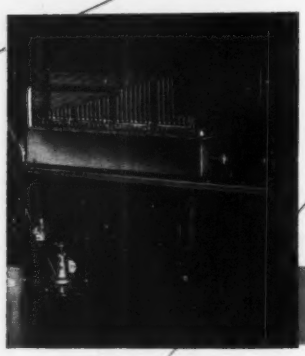

Manzel lubricates Bliss Press.
What's your problem?

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Insure many years of economical, trouble-free service from all types of machinery with *Manzel* Force Feed Lubrication. Adaptable to numerous difficult oiling problems, "Manzel's" can be engineered to *your* requirements. Experienced representatives throughout the country. Just write . . .

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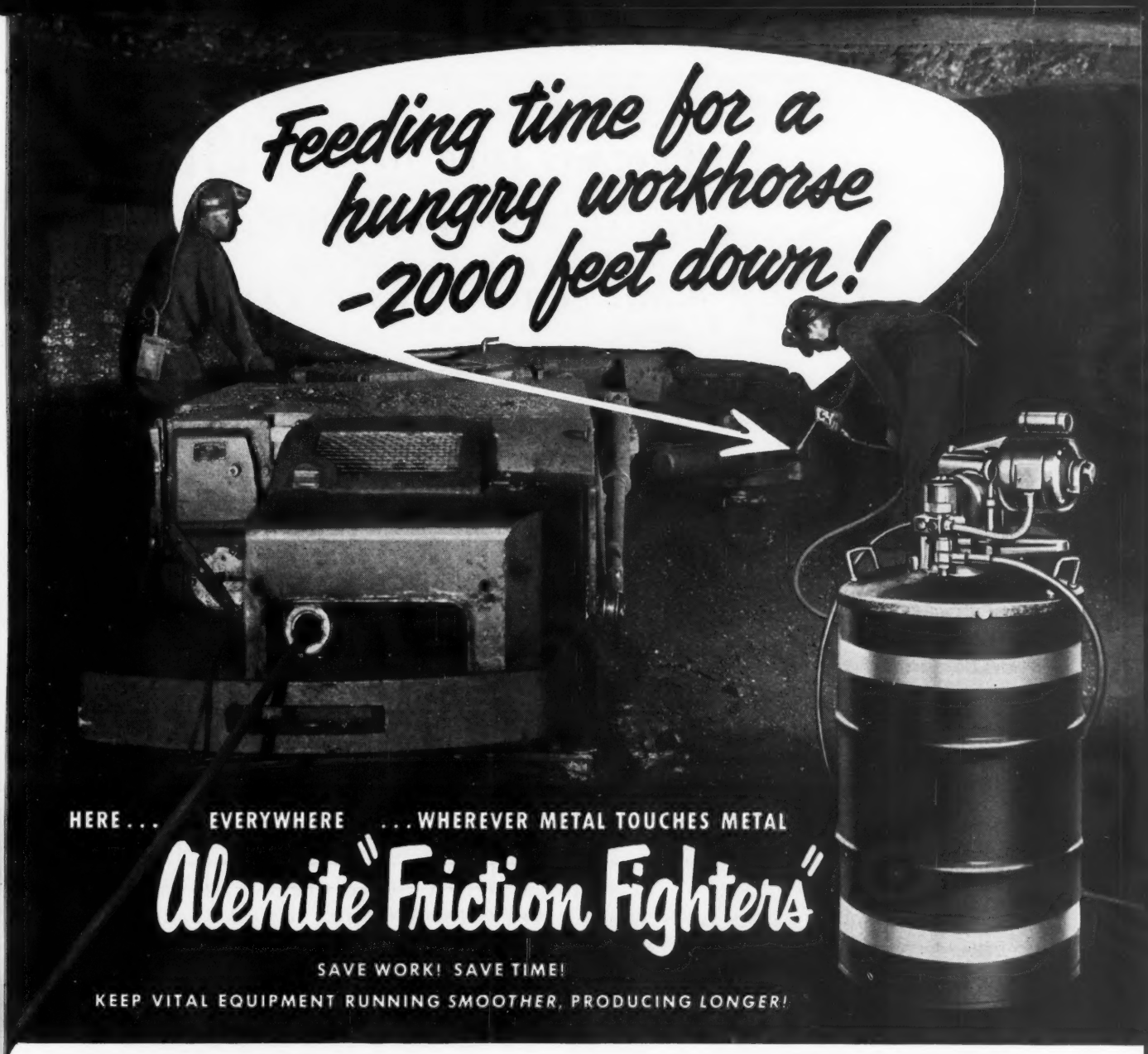

HERE... EVERYWHERE ...WHEREVER METAL TOUCHES METAL

Alemite "Friction Fighters"

SAVE WORK! SAVE TIME!

KEEP VITAL EQUIPMENT RUNNING *SMOOTHER*, PRODUCING *LONGER!*

Alemite Helps Slash Maintenance Costs!

By protecting vital moving parts, you end bearing failures in advance! Alemite barrel pumps have the power and "push" to thoroughly flush-out old grease and gritty coal dust from bearing surfaces. Help keep equipment running longer—at less cost!

Alemite Assures Clean, Safe Lubrication Fast!

Below ground or above ground, there is a better Alemite method for transferring, loading or applying grease. Refinery-sealed lubricants are kept clean. You save time...save grease...save work.

Alemite Reduces "Downtime" . . . Saves Man Hours!

Faster, easier Alemite methods reduce machine "downtime" for lubrication. Help increase coal tonnage. Bring you pumps that can be powered with air or electricity, for use in shaft and strip operations or in coal preparation.

ALEMITE

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Lubrication Methods that Cut Maintenance Costs

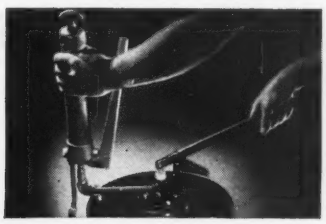
A PRODUCT OF SW STEWART-WARNER

Barrel to bearing — Alemite cuts costs three ways

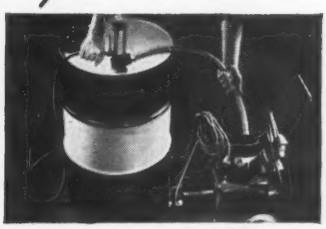
There's An Alemite Pump Just Right For Your Job!

Check today with your local Alemite supplier or write Alemite, Dept. P-82, 1850 Diversey Parkway, Chicago, Illinois.

1. In Applying Lubricants . . . by saving up to 23.9 man-hours for every 100 pounds of lubricant applied to bearings.



2. In Loading Grease Guns . . . by saving 3¾ man-hours for every 100 pounds of lubricant loaded into hand guns.



3. In Transferring Lubricants . . . by cutting man-hours 63% for every 100 pounds of lubricant transferred.

Who has tried it?

Has it been successful?

What can new users expect?

PALMOSHIELD

Six months ago Palmoshield was introduced to readers of this magazine as the first workable replacement for imported palm oil in cold rolling operations. At that time we listed four advantages for the new lubricant.

1. Palmoshield is produced in the heart of the steel industry. Users are not dependent on overseas shipment.
2. Palmoshield is made from domestic materials so freely available as to supply all American steel production.
3. Palmoshield need not be stockpiled by the user, yet it does not deteriorate in storage.
4. Palmoshield is subject to exact chemical control. You can specify free fatty acid content to ½%—and get it.

The record of the past six months in various types of cold rolling operations have fully justified each of these claims.

Mill Use Establishes Two New Benefits

On the basis of orders delivered and actual mill experience, we feel Palmoshield now offers new users two additional advantages:

To Purchasing Agents. The price of Palmoshield is not artificially controlled. It rises and falls freely with the domestic fat market. In the past six months users have received five voluntary price cuts totaling 33%.

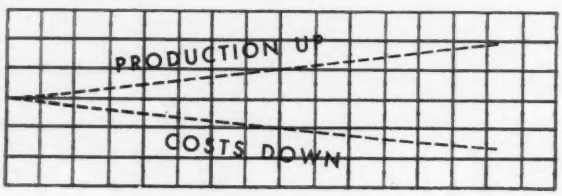
To Operators. Mill experience indicates that the use of Palmoshield improves production.

Palmoshield requires absolutely no changes in rolling mill operation.

Use of Palmoshield results in quicker to gauge in better shape.

Water break tests show that Palmoshield washes grease-free under conventional cleaning operations.

The result—increased tonnage at less cost.



Quick Acceptance by Major Steel Producers

Public "name dropping" is not our policy. But we can state that nearly two-thirds of the major tin plate mills in this country and Canada are now using Palmoshield either in regular mill operation or for on-the-job test runs, and with uniformly satisfactory results. On request, an Ironsides representative will give you, in person, case-history facts on Palmoshield to help you decide whether to test this new lubricant in your mill.

Palmoshield is available for same-day shipment in 55-gallon drums and tank car lots. For details write The Ironsides Company, 270 West Mound St., Columbus, Ohio.

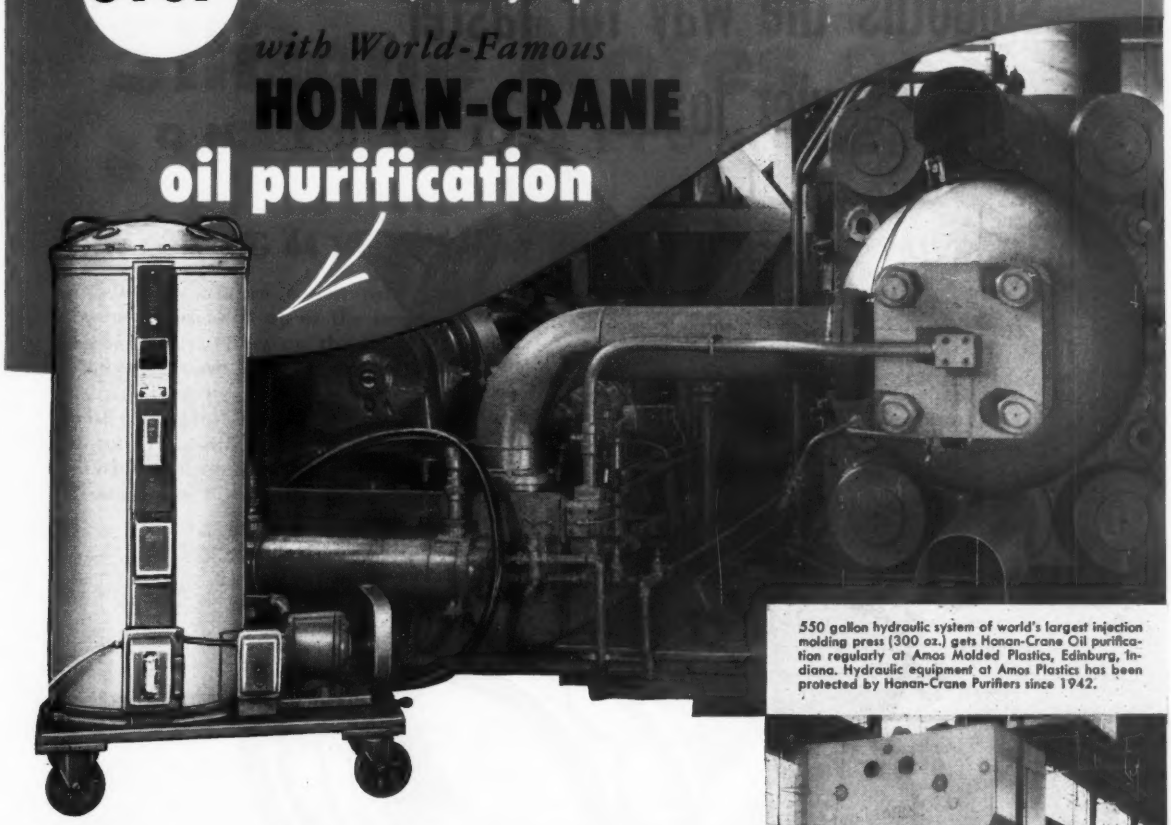
SPECIAL LUBRICANTS and PRESERVATIVES

IRONSIDES SHIELD PRODUCTS **PALMOSHIELD**

STOP downtime, costly repairs on HYDRAULIC EQUIPMENT

with World-Famous

HONAN-CRANE oil purification

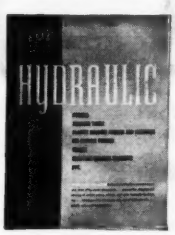


550 gallon hydraulic system of world's largest injection molding press (300 oz.) gets Honan-Crane Oil purification regularly at Amos Molded Plastics, Edinburg, Indiana. Hydraulic equipment at Amos Plastics has been protected by Honan-Crane Purifiers since 1942.

70% of Trouble on Hydraulic Equipment Is Caused by Oil Contamination and Failure

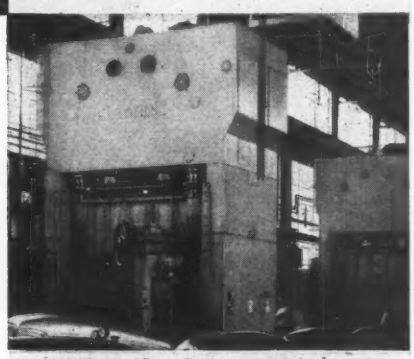
Honan-Crane Purifiers prevent trouble before it starts in hydraulic installations by keeping oil clean and free from damaging contamination. When used to replace ineffective methods or where no purification has been practiced previously, 50% reduction in hydraulic maintenance costs and 4 to 5 times the former safe oil life are common experiences.

Honan-Crane Purifiers prevent excessive wear of hydraulic pump parts . . . prevent clogging and sticking of control valves, pistons and other hydraulic mechanism . . . greatly extend the safe-use life of hydraulic oils Specify Honan-Crane Oil Purification for your hydraulic equipment. Proven by years of dependable service throughout the world . . . there's no reason to settle for less!



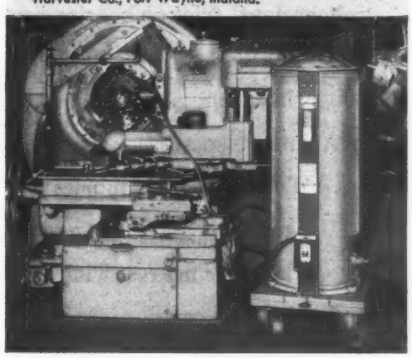
FREE! 8-page "Hydraulic Bulletin" with case histories describing profitable advantages of Honan-Crane Purification in many critical hydraulic applications. Write for your copy!

All Honan-Crane equipment is sold on a performance guaranteed basis



ABOVE: Honan-Crane Purifiers maintain clean oil for battery of giant hydraulic presses in prominent automobile body-parts plant.

BELOW: Honan-Crane Purifier maintains clean hydraulic oil in 80 to 90 metal working machines at International Harvester Co., Fort Wayne, Indiana.



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"Tycol Armitage boosts bearing life... smooths the way for faster, heavier loads"

Of course! Tycol Armitage Bearing Grease "stays put" ... keeps anti-friction bearings running smooth and cool. Its high stability makes it suitable for sealed anti-friction bearings that must last the life of the equipment.

Tycol Armitage possesses exceptional resistance to oxidation.

The dependable lubricating ability of this quality grease lengthens bearing life and cuts down maintenance costs.

Call your nearest Tide Water Associated office for further information.

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DOW CORNING

Silicone Notes

ON LUBRICATION

REFERENCE NO. SL-53

FILE SILICONE LUBRICANTS

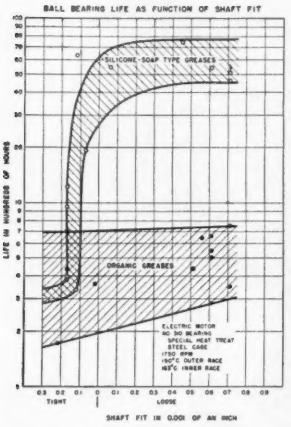
Make sure you have basic data sheets BG-2, 5501b, 7102. If misplaced write Dept. BW-20

DOW CORNING CORPORATION
Midland, Michigan

DOW CORNING 44 SILICONE GREASE

In electric motors which may operate hot, the mechanical fit-up of the bearing assembly has a critical effect on the life expectancy of silicone grease. This was proved by life-testing various greases in the bearings of totally enclosed non-ventilated induction motors operating at high temperatures. The relation between shaft-fit and life in hours is shown in Figure 1.

FIGURE 1
BALL BEARING LIFE AS FUNCTION OF SHAFT FIT



In the TENV induction motors used to test bearing life at 150°C., these curves indicate that the life of Dow Corning 44 lubricated bearings with a shaft-fit of 0.2 mils loose is about 15 times the life of identical bearings with a shaft-fit of 0.2 mils tight.

These data show the importance of mechanical fit-up. A tight shaft-fit, for example, may take up most of the radial clearance in the bearing. Where the inner race operates at a higher temperature than the outer race, unequal thermal expansion may put the balls under compression. Any combination of mechanical fits which produces radial clearances inadequate at operating temperatures, or poor bearing alignment, will subject the grease to extreme pressures and result in unsatisfactory bearing life.

The subject of Design Considerations for Optimum Performance of Silicone Greases in Ball Bearings is more fully developed in a paper recently read before the ASLE. Write for a copy.

DOW CORNING VALVE SEAL A

With a solidification point below —40°F. and no true melting point, Dow Corning Valve Seal A is unique among valve lubricants for its stability at both high and low temperatures and for its resistance to oxidation. It is generally inert chemically and physiologically; shows excellent resistance to hot water and to a wide variety of chemicals and gases.

The usefulness of Dow Corning Valve Seal A in chemical services too severe for conventional lubricants is indicated by tables recently published in a new data sheet describing its performance in valves handling more than 120 different chemicals and gases. Here's a representative sample taken from actual field service experience:

Reagent	Temperature, °F.	Rating
Brine (caustic)	Hot	Good
Calcium chloride (molten), 100%	327	Good
Sodium hydroxide, 60%	300	Fair
Sulfuric acid, 98%	77	Good
Lubricating oils	----	Good
Chlorinated phenols	Hot	Good
Slurry of aluminum chloride, benzoyl chloride and paraphenyl phenol	347	Good
Slurry of potassium dichromate, sodium chloride and sodium sulphate	265	Good
Acetylene	----	Good
Ammonia (liquid)	----	Good
Hydrocarbon gas	—120 to 500	Good

There are, of course, too many variables to permit specific recommendations. The tables from which these examples were taken do serve, however, to establish the fact that Dow Corning Valve Seal A is used successfully in many services where the life and reliability of valves is severely limited by failure of conventional lubricants.

***For example: In the valves of large turbines,* an electrical manufacturer recommends the use of Valve Seal A under pressures as high as 400 psi and temperatures ranging up to 750°F.**

WRITE TODAY for more information on Dow Corning Valve Seal A. Please address Department BW-20 and ask for data sheet No. VSA-1.

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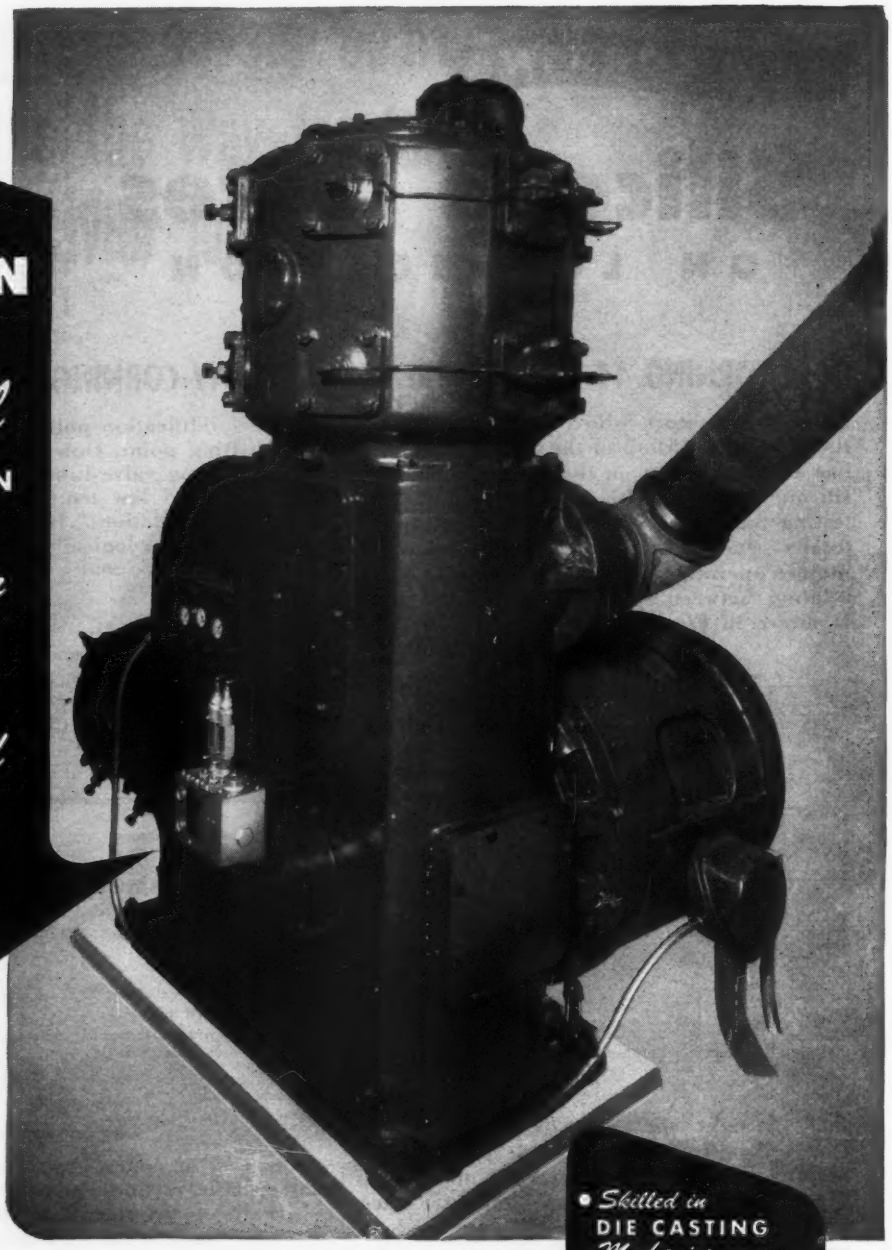
CANADA: Fiberglas Canada Ltd., 50 St. Clair Avenue west, Toronto, Ontario ENGLAND: Midland Silicones Ltd., 49 Park Lane, London, W.1

MADISON -KIPP *fresh oil* LUBRICATION

fed under pressure by the measured drop!



Illustrated, the Madison-Kipp Model SVH Lubricator on an Ingersoll-Rand XLE Compressor.

- *Skilled in* DIE CASTING *Mechanics*
- *Originators of Really High Speed* AIR TOOLS
- *Experienced in* LUBRICATION *Engineering*

....STANDARD EQUIPMENT ON COMPRESSORS, WORK ENGINES AND MACHINE TOOLS....

Oil under pressure fed drop by drop from a Madison-Kipp Lubricator will definitely increase the production potential for years to come when applied as original equipment on new machine tools, work engines and compressors. There are six popular models for every application. Write for special engineering data for your particular requirement.

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ANCIENS ATELIERS GASQUY, 31 Rue du Marais, Brussels, Belgium, sole agents for Belgium, Holland, France, and Switzerland.

WM. COULTHARD & CO. Ltd., Carlisle, England, sole agents for England, most European countries, India, Australia, and New Zealand.

Now—One grease will service all grease applications in the majority of plants

Gives ALL THESE PLANT SAVINGS:

1. **Extends TIME between greasings**—lasts longer . . . stays in bearings longer.
2. **Low-cost application**—fewer servicings and *only the one grease* to handle.
3. **Simple inventory**—Shell Alvania Grease replaces up to 20 brands formerly required.
4. **Better protection**—against heat, cold and moisture.
5. **Greater safety**—less chance of applying the wrong grease!

Gives ALL THESE LUBRICATION ADVANTAGES:

1. **Higher mechanical stability** than any conventional grease at operating temperatures.
2. **Pumpable at low temperatures**—even in unheated storage.
3. **Stable at high temperatures**—superior to the best "soda" greases.
4. **Impervious to water**—excellent resistance to washing out.
5. **Longer service life**—reduced consumption.

The "MILLION-STROKE" Industrial Grease!

A grease that will stand 100,000 punishing strokes of the ASTM Work Tester has been considered a superior lubricant.

In a deliberate attempt to break down Shell Alvania Grease, *on the same tester* the run was extended...200,000 strokes...300,000 strokes . . . 500,000 strokes! Finally, at one million strokes the test was discontinued, because this grease *would not break down*—it was still a fit lubricant both in appearance and consistency.

SHELL OIL COMPANY

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SHELL®

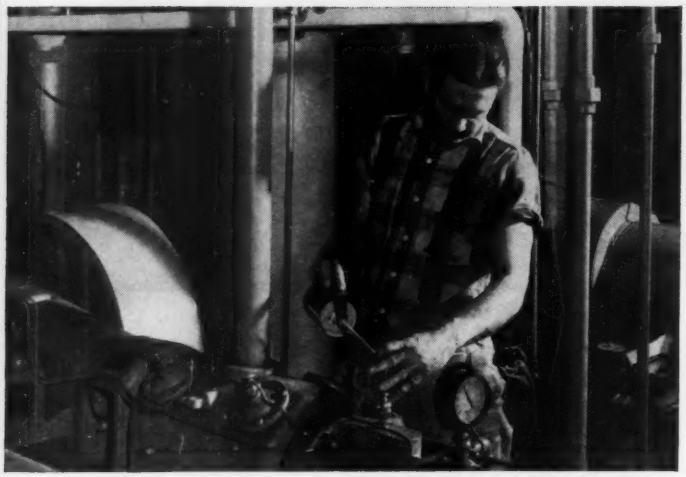
SHELL ALVANIA . . . The "MILLION STROKE" Grease

PARTS REPLACEMENT DRASTICALLY REDUCED. Checking his records after 17 months' top performance from Sun Rock Drill Lubricant, the operator of this Pennsylvania mine found that parts replacement had been reduced 67 percent. The product he had used before kept running off the drills, and downtime was excessive.

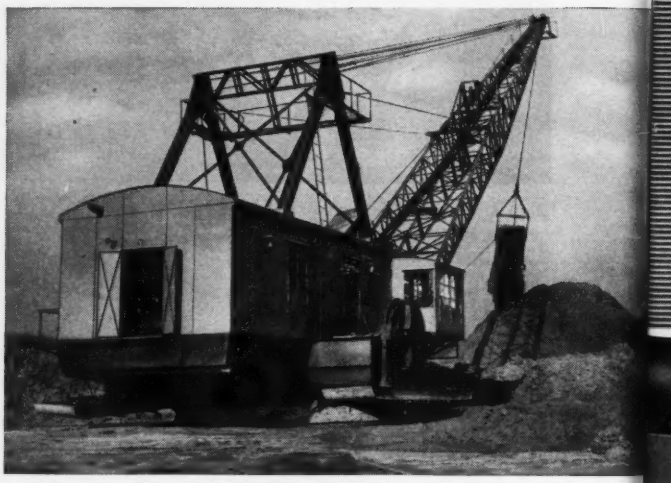
PRODUCTION UP, LABOR COSTS DOWN. Gummy deposits in the transmission case and heads forced the operator of this mine to shut down his loader every two or three days. Changing to a Sun "Job Proved" product, he now has to grease it only every two or three weeks, and he estimates his savings on maintenance at over $1,600 a year.

SUN PRODUCTS GET THE JOB DONE

These four examples show how



14 YEARS UNDER PRESSURE AND GOING STRONG. This compressor has been running 16 hours a day ever since its installation, and is working as well as ever. From the start, a Sun lubricant has been used for the crosshead and air cylinder. No hard carbon has formed, and during the past five years there has been only one shutdown—when a different brand of oil was used by mistake.



DIESEL PERFECT AFTER 13,680 HOURS. Thanks to the constant protection of Sunvis H.D. 700 Oils, the pistons were clean, the oil grooves open, the rings free. No signs of seizure or scoring of skirts. Not one of the cylinders showed more than 1/1000 inch wear, the bearings were perfect, the entire engine was clean and free of sludge or varnish. Analysis of the oil showed it to be in good condition.

For further information or the services of a representative, call the nearest Sun Office

SUN INDUSTRIAL PRODUCTS

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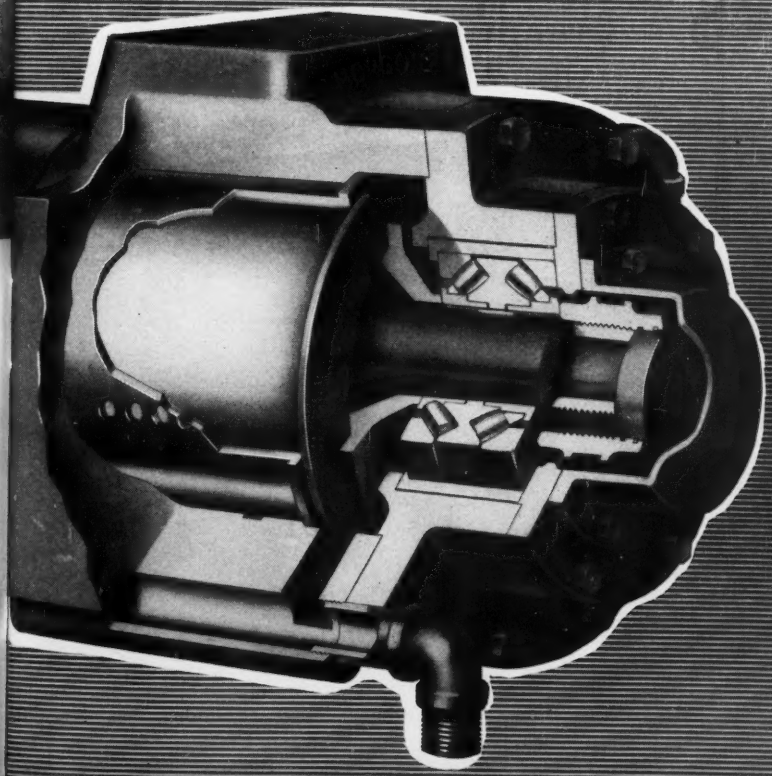
SUNOCO®

MORGOIL
ROLL NECK BEARINGS

Aluminum Alloy bushings have been tested in MORGOIL Bearings on all types of 2-high and 4-high mills, in the plants of many of our customers and have definitely proven their superiority under the most grueling of operating conditions . . . . .

They are now supplied as standard equipment.



MORGAN CONSTRUCTION CO.
WORCESTER, MASSACHUSETTS

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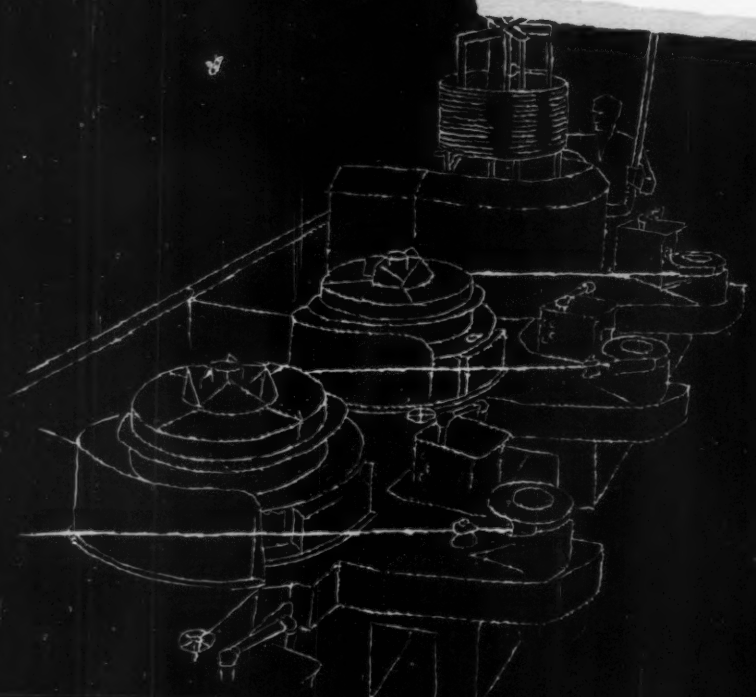


Lube Lines

FIRST NATIONAL SYMPOSIUM

The ASLE First National Symposium, in conjunction with the Centennial of Engineering, on Fundamentals of Friction and Lubrication in Engineering, will be held September 8 and 9, 1952, at the Bal Tabarin, Hotel Sherman, Chicago, Ill. The schedule and agenda for the sessions is as follows: Monday, Sept. 8, 10:00 A.M., Historical Development of Modern Lubrication Concepts, Discussion Leader: D. D. Fuller, Columbia University, Discussors: A. Bondi, Shell Development Co., J. Boyd, Westinghouse Electric Co.; Monday, Sept. 8, 2:00 P.M., Fundamentals of Hydrodynamic Lubrication, Discussion Leader: M. D. Hersey, U.S. Naval Engineering Experiment Station, Discussors: S. J. Needs, Kingsbury Machine Works, H. Poritsky, General Electric Co., E. K. Gatcombe, U.S. Naval Post Graduate School; Tuesday, Sept. 9, 9:00 A.M., Physics and Chemistry of Rubbing Solids—Basic Principles, Discussion Leader: R. G. Larsen, Shell Development Co., Discussors: R. H. Savage, General Electric Co., E. Rabinowicz, Massachusetts Institute of Technology; Tuesday, Sept. 9, 1:30 P.M., Physics and Chemistry of Rubbing Solids—Technical Applications, Discussion Leader: M. C. Shaw, Massachusetts Institute of Technology, Discussors: W. E. Campbell, Bell Telephone Laboratories.

ENGINEER SHORTAGE[1]

The U.S., the world's greatest technological civilization, is running short of engineers. For years it looked as if there would be a glut, not a shortage. Engineering students used to spend their last spring in college like any other seniors: looking for jobs. But today industry competes for their services with the fierce cunning of Hollywood star-snatchers; they are wooed by eager personnel men, treated to lavish dinners, whisked off on inspection trips to factories. Most engineering graduates have at least half a dozen offers, with an average starting salary of $350 a month.

Enrollment in engineering schools is only slightly more than in 1940, while industry's demand has increased tremendously under the impetus of war production. Worried industrialists also blame: 1) the low birth rate of the '30s, which has kept college classes limited; 2) the armed forces, which snatch many engineering students before private industry gets them (the greatest concentration of M.I.T. graduates in the world now works at Wright-Patterson Air Force Base); 3) a wrong steer (fostered by prophetic experts) that engineering would soon be an overcrowded profession. Westinghouse statisticians calculate that in 1900 only one engineer was needed for every 250 workers in industry, by 1930 it took one engineer for 100, and soon one engineer will be needed for 50.

What can be done? Educators and industrialists suggest some remedies: Engineers should be more wisely and efficiently used in industry. Women should be encouraged to go into certain types of engineering jobs. Last year, of some 40,000 engineering degrees granted, only 77 went to women. High-school students with some technical schooling should be persuaded to continue at engineering schools rather than take high-paying jobs right away. Despite industry's frantic efforts, the demand for engineers will continue to outstrip the supply—unless a sudden, unlikely end to world tension should bring a cutback of war production. The class of '52 (has graduated) into a technicians' world and an engineers' market.

[1]Reprinted in part from TIME, April 21, 1952, p. 85-86

PROFESSIONAL DEVELOPMENT[2]

Participation in technical-association activities is one of the important steps in professional development. The following policy has executive approval in the Westinghouse Research Laboratories and is cited here as being typical of the outlook of the majority of well-managed companies: (1) Active participation in engineering societies by every qualified employee should be encouraged; such participation should be regarded as part of the man's normal and regular work. (2) A good engineering development job is not finished until the noteworthy engineering uncovered has been (a) presented at the proper time before a national technical society, and (b) that the pioneering knowledge of the company is made part of the permanent engineering literature. (3) Membership in at least one engineering society is a definite responsibility of any company employee who regards himself as a member of the engineering profession.

[2]Reprinted in part from MECHANICAL ENGINEERING, June 1951, p. 491

PHYSICAL CHARACTERISTICS OF LUBRICANTS[3]

All fluid lubricants have certain physical characteristics that can be determined in the laboratory, such as specific gravity, which is the weight of the oil as compared to the weight of a similar amount of distilled water. The flash and the fire points denote the temperature at which vapours are emitted that form a lean mixture with the air and can be ignited to produce a flash. At a higher temperature more vapour is emitted and the mixture burns steadily. The cloud test represents the temperature at which wax begins to form in the paraffin oils. The pour test is determined by the temperature at which the oil ceases to flow. The "fluidity" of the oil at various temperatures is the measure of its viscosity. The carbon residue test indicates the percentage of residue left after the oil has been completely burned. Saponification and emulsification values, acidity, colour and many other tests are also made.

The fixed lubricants, that is, the animal or vegetable oils, have a viscosity curve that is a characteristic of the oil and indicates its source. The mineral oils can be made of any desired body or viscosity at any temperature by methods of distillation or by blending the heavy-bodied with the light-bodied lubricants. Viscosity is a necessary feature of an oil's ability to support loads; it is also a measure of its internal friction and an indication of its film thickness. The amount of frictional resistance to the motion of machinery is entirely dependent upon the viscosity of the lubricant and its suitability for the conditions under which it has to work. The heat generated in a bearing, if it all could be collected and measured, would be found to be the precise measure of the power lost in overcoming the solid friction of the dry surfaces moving on each other or of the fluid friction of the lubricant between such surfaces. This heat, as it develops, flows out through the metal and is radiated to the air, its rate of flow being dependent upon the construction of the bearing and the kind and location of the machine.

All oils change in viscosity with the application of heat though not all of them to the same degree at lower temperatures because of the nature of the crudes from which the mineral oils are made, as well as some of the methods of manufacture. The viscosity also increases with the increase of bearing pressure. The varying viscosity of the oils through the effect of heat and pressure is the most important item to be considered in making applications of the lubricants to practical operations. Every bearing requires a certain amount of time to work to a steady temperature above that of the surrounding atmosphere; after that it will

(Continued on page 197)

[3]ENCYCLOPAEDIA BRITANNICA, 1949, Vol. 14, p. 452

COAL MINE LUBRICATION*

by C. W. Thompson
National Mines Corp. &
Weirton Coal Co.
Morgantown, W. Va.

Mr. Thompson first started working as a coal miner on the night shift while attending high school. After high school he continued working in coal mines as motorman, electrician, section foreman, etc., while completing correspondence courses in Mining Engineering and Electrical Engineering. His experience continued through General Mine Foreman of mechanized mines to Superintendent and General Superintendent. In 1947 he became affiliated with the Weirton Steel Co. & National Steel Corp. as Research Engineer of mining properties and was promoted successively to Assistant Manager and Manager of the National Mines Corp. & Weirton Coal Co., subsidiaries.

ABSTRACT: The production of any mine depends on the continued operation of all machinery, and management realized that lubrication plays an important part in keeping this equipment in operation with the least number of breakdowns.

Much help in lubricating mine equipment can be derived by selecting an oil supplier that has a competent engineering staff. They have studied the various manufacturers' recommendations and have found by exhaustive study, by careful testing and actual application, that by selecting a small number of high quality products more efficient lubrication can be accomplished.

Lubrication is always a contributing factor to efficient operation of mechanical equipment. Since mines are becoming more mechanized, lubrication is of major importance to the coal operator. The proper lubrication of these machines is necessary to achieve maximum production and lower maintenance costs.

The lubrication of underground mining equipment presents problems not usually encountered in other industries. The design of the machine is governed by the height of the coal vein in which it is to be used. Because of this restriction, the machines are compact and often incorporate sliding mechanisms and gears in one housing both of which must be lubricated by one lubricant. In addition, the presence in the mine atmosphere of abrasive dusts and corrosive compounds makes lubrication more difficult and requires a planned program for lubrication as well as preventive maintenance.

The proper lubricants should be selected and applied according to a planned lubrication schedule. If improper lubricants are selected and applied in a careless manner, maintenance costs will increase and production will go down due to equipment breakdowns. Even with the best grease, a bearing can be over-lubricated. This not only wastes grease, but can result in broken grease seals. Failures often occur in electric motors due to over-lubrication of the armature bearings by allowing the grease to get into the windings. This is a very costly breakdown that can be eliminated by a little care.

In coal mines a variety of equipment is used. This equipment is classified as "underground" and aboveground" equipment. Time will not allow the discussion of every piece, but some of the more important pieces will be discussed briefly. The "aboveground" equipment will be discussed first.

* Paper presented at 7th Annual Meeting, ASLE, Cleveland, April 7, 1952

TIPPLE AND WASHERY

Modern coal tipples and cleaning plants handle and clean the coal after it is brought from underground. Electric motors of various sizes, shaker screens, vibrating screens, filters, conveyors, washers, air compressors, blowers, crushers, speed reducers, water pumps, etc., are used in these plants. The electric motors may be equipped with ring-oiled journal bearings or with anti-friction bearings. A good quality oil of approximately 300 seconds at 100 F (SAE #20) with appropriate pour point or a high-quality, soft ball-and-roller-bearing grease should be used, depending upon the type of bearing.

The grease fittings on conveying and coal handling equipment can be lubricated with a soft general-purpose grease. Enclosed speed reducers of the spur, helical and herringbone types are satisfactorily lubricated with a light-bodied gear-lubricant of good quality. In general, worm gears should be lubricated with a straight mineral oil or a compounded steam-cylinder oil.

It will be necessary to study the other equipment before selecting the proper lubricants because there are many types and makes being manufactured and sold.

In general, these plants are usually hand lubricated by pressure gun, but the centralized greasing systems are gaining favor with the coal operators. Some of these systems are completely automatic and others semi-automatic. When centralized systems are used, a thorough study should be made of the bearings to be lubricated, and the bearing that is the most difficult to lubricate should govern the type of lubricant to be used in the greasing system.

The other aboveground equipment consists of machine shops, transformers and oil-type switches, crushers, trucks, tractors, compressors, conveyors, etc. If stripping is being done, dozers, shovels, draglines, scrapers, trucks, compressors, high wall horizontal augers, drills, etc., will be involved.

The machine shop can usually be lubricated with an oil of from 300 to 500 saybolt universal-seconds at 100 F (SAE #20 or #30), a light gear-lubricant and a ball-and-roller-bearing-grease of good quality.

For transformers and oil-type switches, a light high-quality transformer oil should be used.

Conveyors and crushers are lubricated the same as they are in the cleaning plant or tipple.

If stripping equipment is being used, the following lubricants will be needed: A motor oil suitable for both gasoline

and diesel engines, a good-grade gear-lubricant for gear-boxes, chain-drives, etc., a high-quality air-compressor oil that can also be used for hydraulic systems, a good general-purpose grease that has a high melting-point to take care of the hot bearings on shovels and draglines, a track-roll lubricant that will protect the rollers working in the mud and water, a good wheel-bearing grease with a high melting point for truck wheel-bearings and an exposed-gear lubricant for the exposed gears on shovels and draglines. If any of the equipment is equipped with torque converters or hydraulic couplings, then a specially made lubricant will be needed.

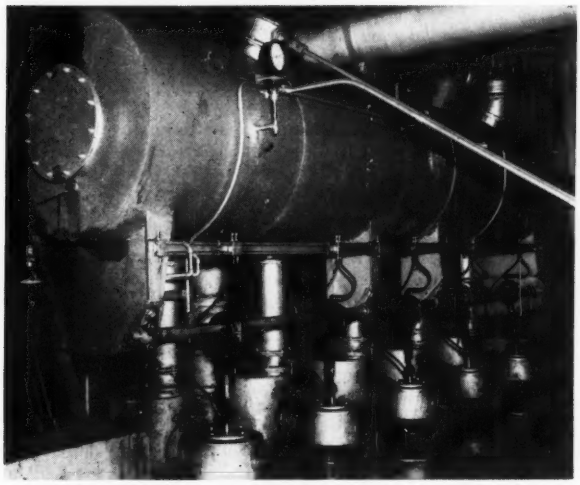


Fig. 1 Automatic lubrication system on air pulsation valves of wash boxes in Washery

The high-wall horizontal-augers can usually be lubricated with the same lubricants used on the strip operation.

In lubricating aboveground equipment, consideration must be given to summer and winter operation as seasonal grades of lubricants usually are required.

In discussing underground equipment it should be pointed out that this equipment is the hardest type to lubricate at a coal mine. Not only from the standpoint of the conditions it has to work under, such as mud, water, coal dust and dirt, but from the standpoint of the actual application of the lubricant. This is particularly so in low coal where the greaser has to crawl on his hands and knees to reach the machine.

The methods of applying the lubricants to the various machines differ at the different mines. In some mines the machine operator lubricates the machine he operates, in others the mechanic lubricates all the equipment on his section. This mechanic is supervised by the section foreman or chief electrician. In still other mines the equipment is lubricated by greasers who are responsible for the lubrication of all underground equipment.

Within the last two years, centralized greasing systems have found their way underground and are now operating successfully on shuttle cars, loaders, cutting machines, and locomotives. Some of these are completely automatic and others semi-automatic. Some use a fluid grease and others a cup-type grease. Management has seen the advantage of this type of application and are now giving favor to the installation of this equipment on both new and used equipment.

The lubrication recommendations of the various equipment manufacturers vary to some extent as to the lubricants they recommend for their particular machines. These should be studied carefully and the least number of products that will lubricate the machines satisfactorily should be selected. This eliminates waste, misapplication of product, cuts inventory and assures better overall lubrication.

CUTTING MACHINES

Cutting machines are grouped in two classes, the bottom cutter (shortwall) and the Universal type which will shear either side or cut top and bottom or any point in between. These machines are equipped with plain, anti-friction and, in some cases, waste-packed bearings. Some have cutter-head mechanisms and transmissions which are enclosed and operate in an oil bath.

Coal cutting is a heavy-duty operation which imposes severe loads upon gears, bearings, chains and lubricants. These machines can be efficiently lubricated with a soft general-purpose calcium-base grease of about a #1 or #2 consistency and a general-purpose mineral oil of about 65-100 S. U. seconds at 210 F. A good-grade gear-lubricant should be used in gear cases. If cases have sliding mechanisms, an oil of about 600-800 S. U. seconds at 100 F should be used. This should be a straight mineral oil. If the machine is hydraulically equipped, a good grade hydraulic oil of about 300-500 S. U. seconds at 100 F is satisfactory.

LOADING MACHINES

As loading controls the rate of production it is one of the most important operations in mechanized mining. The loading machine loads the coal onto the shuttle car, mine car or conveyor as the case may be.

These machines have essentially the same requirements as to lubricating and hydraulic oils as similar components on the coal cutting machines.

SHUTTLE CARS

Shuttle cars are used to transport coal from the various working faces to the loading point for conveyors or mine cars. Two shuttle cars are usually used for each coal loader. These cars vary in size from about 3 to 8 tons capacity and are electrically driven.

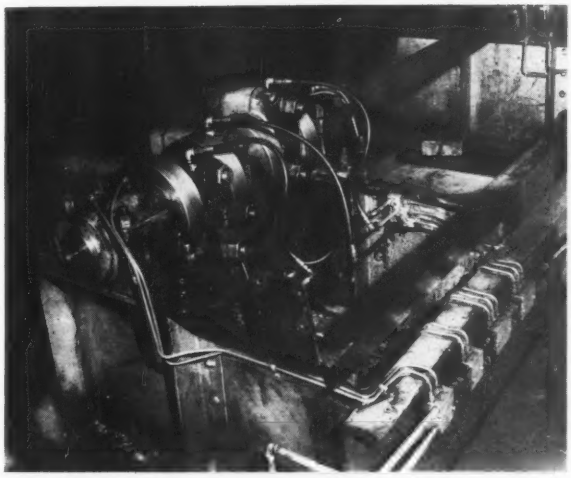


Fig 2 Automatic grease system on crank shafts of classifying screens in Washery

The selection of lubricants for the transmissions, speed reducers, hydraulic systems, and grease lubricated bearings is essentially the same as that for the loading and cutting machine.

As mentioned above, some of these cars, as well as loading and cutting machines, are now being equipped with centralized greasing systems with good results. The shuttle cars have from 35 to 70 points connected in the system according to the type of installation. Some are automatic

and others are semi-automatic. One manufacturer has a completely automatic unit that lubricates the entire shuttle care with twenty turns of the steering wheel in either direction.

CONTINUOUS MINERS AND COLMOLS

These machines represent a new development in underground mining. They eliminate cutting, drilling and shooting. They cut the coal from the face and load directly onto the shuttle car, conveyor, etc.

Due to the dual functions performed by these machines, there are more transmissions and motors than on a single function machine, but their lubrication requirements are similar to those of the equivalent components on the loading and cutting machines.

CONVEYORS (BELT & CHAIN)

A conveyor system can be made supplementary to a mine car or hoist system or, in some cases, installed as a primary means of coal handling to the breaker or point of shipment.

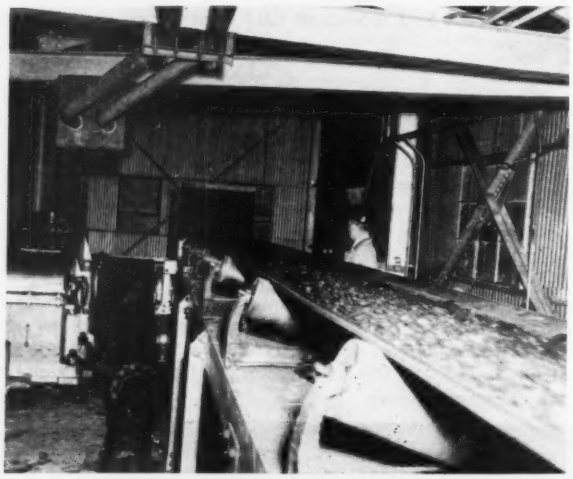


Fig 3 Head end of two-mile conveyor belt where coal is chuted into river barges. Drive motor for belt is on left

The belt and chain conveyors are electrically driven through speed reducers, which in turn drive the belt or chain. These speed reducers can be efficiently lubricated with a light-bodied gear-lubricant if they are spur, helical or herringbone, but a heavier lubricant is necessary if they are worm-gear units. The conveyor rolls and other bearings can be lubricated satisfactorily with the same general purpose grease as used on other underground equipment.

MINE CARS

There are millions of mine cars in service today. They are used to bring the coal from underground. The lubrication of these mine car wheels is of great importance since free-rolling wheels are necessary to allow the maximum number of cars to be hauled in one train. Whether they are plain oil, cavity or anti-friction type, lubrication is the deciding factor in determining ultimate life, maintenance cost and time out-of-service for repairs.

The anti-friction-equipped-wheels require a soft calcium-base grease of about a #1 or #2 consistency. The cavity type requires a softer semi-fluid grease and the oil type requires a heavy oil. Because these cars sometimes operate in water, a calcium-base grease should be used.

LOCOMOTIVES

Mine locomotives are generally operated by electric power from trolley or storage batteries. They operate under much the same conditions as do mine cars. Their lubrication requirements are, therefore, similar to other underground equipment.

AUGER MACHINES

Underground augers are relatively new in underground mining, but offer high productivity per man. The horizontal auger has made a place for itself in the strip pits, and now it is moving underground for both thick—and thin-seam coal. Like other underground equipment it is compactly built. Its lubrication is similar to other underground equipment in that it is equipped with gear cases, plain and anti-friction bearings.

FANS

Proper ventilation is necessary at all times. This is accomplished with mine fans located at the outcrop. These fans are equipped with safety signals and sirens as a safety precaution in case of power or mechanical failure. They are usually driven by an electric motor. These fans are equipped with either ring-oiled journal or anti-friction bearings. A good quality oil of about 300 S. U. seconds at 100 F with a low pour point is correct for ring-oiled bearings, and a high-quality soft ball-and-roller-bearing-grease is necessary for anti-friction bearings.

There are many other pieces of equipment used underground such as coal drills, water pumps, compressors, rock dusters, trolley tractors, etc., that require lubrication. These can usually be lubricated with the same lubricants as used on the other machines.

Since most all underground equipment is driven by electric motors, care should be taken to see that they are lubricated with the proper grease. A high quality soft ball-and-roller-bearing-grease is necessary for effective lubrication. To keep these from being lubricated with the general purpose grease used underground, a different type grease fitting can be installed so that the general-purpose grease-gun will not fit. Electric motors are only lubricated periodically.

STORAGE AND HANDLING OF LUBRICANTS

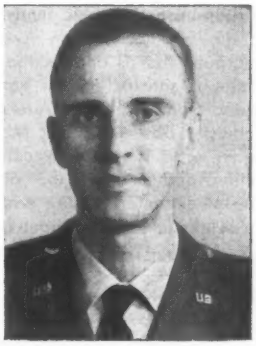
Efficient storage and handling of lubricants is equally as important as the selection and proper application of suitable grades. The oil and grease storage house should be located as centrally as possible to railroad and trucking facilities in order to save time and unnecessary handling, together with easy access to various parts of the mine. All containers should be kept covered except when removing lubricant as contamination is one of the worst enemies to be dealt with in a mine. All dirt and coal dust should be wiped off fittings or oil holes to prevent, as much as possible, the entry of foreign matter into bearings.

The whole story on storage and handling of lubricants is to keep them clean and free from contamination so when they are applied they will protect the bearings properly.

STEEL MILL LUBRICATION FROM MANAGEMENT'S POINT OF VIEW by T. R. Moxley, Steubenville Works, Wheeling Steel Co., will be featured in the October issue of LUBRICATION ENGINEERING as the third in the series of Practical Lubrication articles. At the conclusion of this series, the Society will publish the papers in book form as another of its practical lubrication manuals.

THE DEVELOPMENT OF A TURBO-PROP SYNTHETIC LUBRICANT*

by L. D. Christensen
Materials Lab., Research Div.
Wright Air Development Center
Dayton, Ohio



Capt. Christensen is a graduate of the United States Military Academy and Purdue University. Following his work at the latter institution in Chemical Engineering, he was assigned to the Materials Laboratory, Research Division, Wright Air Development Center, Dayton, Ohio, where he is conducting research and development on hydraulic fluids and light oils for aircraft use.

ABSTRACT: Because of the inability of a single petroleum oil to perform satisfactorily at extreme high and low temperatures, a synthetic-base lubricant has been developed for use in the turbo-prop engine. The material is an excellent lubricant, is resistant to oxidation and thermal decomposition at temperatures in excess of plus 400F., and provides for operation in the vicinity of minus 65F. The lubricant consists essentially of a dibasic acid ester with additives to impart other desired properties. The finished fluid contains no extreme pressure additives because of their corrosive and sludge-forming action on certain metals.

Recent engine tests have shown that the lubricant is satisfactory in the power section of a turbo-prop unit. Further engine tests are currently being run to determine whether or not extreme pressure additives in the oil are necessary for satisfactory operation of the reduction gear box.

INTRODUCTION

Since World War II the Air Force has concentrated on the development of more powerful turbine type engines, namely turbo-prop and turbo-jet engines. Where possible this is achieved without appreciably increasing the overall dimensions of the engine. One inevitable result is a higher operating temperature.

In order that the Air Force may operate globally, equipment must function at temperatures down to —65F. Thus the temperature problem in the operation of turbine engines is twofold. The lubricant must be sufficiently fluid at —65F to permit engine starting, and must also perform satisfactorily once the system reaches operating temperature. This places a particular hardship on petroleum lubricants, since the ordinary petroleum oils for engine use are solids at that low temperature. The use of light oil fractions and engine preheating has allowed further use of petroleum oils in currently operating jet engines. Turbo-prop engines present a special problem. Some localized turbo-prop temperatures cause the engine oil to be heated above 400F. This prohibits the use of light petroleum oil fractions because of their oxidative deterioration, evaporation and poor lubricating properties at these high temperatures. At the same time, the critical viscosity requirements of various systems of the engine at —65F prevent the use of heavier oil fractions. In order to provide for both high and low temperature operation with a single oil, a synthetic-base lubricant has been developed for use in a turbo-prop power section and reduction gear box.

No attempt is made in this paper to cover the background work on synthetic lubricants other than to mention that extensive studies were carried out by Zorn[8]. In the United States the Naval Research Laboratory[1,6,7], the Petroleum Refining Laboratory[2,3,4,5], Pennsylvania State College and others have enhanced the knowledge of certain synthetic materials through the early study of the synthetic esters and their additives. The lubricant development for the turbo-prop application was, of course, immeasureably hastened by the use of available fundamental data.

*Paper presented at 7th Annual Meeting, ASLE, Cleveland, April 9, 1952

I APPROACH

From the analysis of the operational requirements of modern turbine engines, development of a lubricant for operation over the temperature range —65F to +400F was desired. A bulk oil operating temperature requirement was estimated to be 180F.

In May, 1949, the Air Force requested the Petroleum Refining Laboratory to undertake the development of a lubricant to withstand the above stringent requirements and suggested the following additional properties as being desirable:

Viscosity, cs. at 210F	4-6
Viscosity Index (min.)	150
Flash Point, °F (min.)	300
Pour Point, °F (max.)	—70
Lubricity	A mild extreme pressure oil

It was desirable to accomplish as much of the development as possible in the laboratory stage without turning to development testing in the engine and gear system until at least a semi-finished fluid was available. An extensive service testing program obviating the laboratory bench testing would have been unreasonably costly in money and time.

In the laboratory development of an acceptable lubricant, it was decided that the principal physical properties to be measured were lubricity and oxidation and corrosion stability, while at the same time providing all other necessary properties. The answers to be derived from laboratory development testing were that the finished fluid would exhibit satisfactory lubricity properties and would retain these properties for reasonable periods of time under high temperature oxidative conditions. In addition, the lubricant was not to corrode the metals that it contacted in the turbo-prop system. In studying the synthetic lubricant field in general, it appeared that the aliphatic diesters had several advantages. Such properties as viscosity index, stability to oxidation and corrosion, viscosity-volatility, availability and others resulted in the decision to place first emphasis on the development of a di-2-ethylhexyl sebacate type fluid[4], and to later investigate current grades of other aliphatic diesters as possible equivalent base stocks. Table I shows some of the properties of a few esters for comparison purposes. Most of these esters are commercial grade, that is, have not been distilled.

II. ANTI-WEAR AND EXTREME PRESSURE EVALUATION

The wear and lubrication properties of a lubricant are obviously important. Therefore, it was desired initially to determine the lubricating efficiency of the esters without anti-wear additives. Following that, work could proceed to the evaluation of the effectiveness of additives incorporated in esters for the purpose of lowering wear rates or preventing scuffing of gears. The Shell Four-ball wear tester was used, on the basis of previous experience, as a convenient laboratory method for studying the wear characteristics of the ester fluids. The values obtained on these esters using the wear tester in the low-load range (1-10 kg.) is comparable to similar data on naphthenic type mineral oils and hydro-

carbon-base hydraulic fluids. In the 1 to 10 kilogram load range, best correlation is obtained with wear in certain hydraulic pumps and on the basis of limited data, this load range is satisfactory for correlating wear noted in a Sunstrand Constant Speed Alternator Drive (equipment in which a diester base lubricant, MIL-L-6387, is performing satisfactorily). This is generally considered the range of anti-wear action, and is below the load range necessary for evaluation of extreme pressure additives. The rusults of wear tests on synthetic esters without additives are shown in Table II.

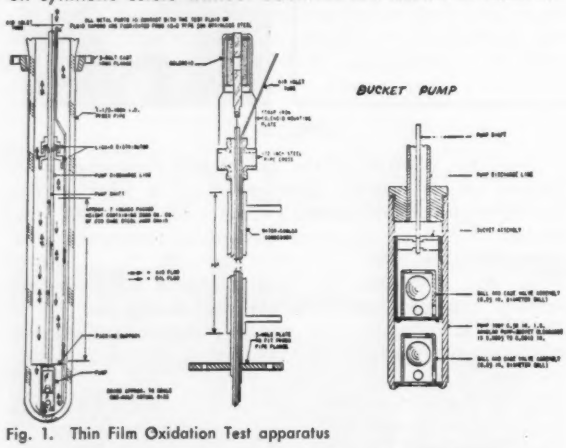


Fig. 1. Thin Film Oxidation Test apparatus

The wear characteristics of the esters themselves are not regarded as being as important as the effect of anti-wear and extreme pressure additives on the esters. Thus, the remainder of the studies on lubricity, relating to the development of a gar box lubricant, dealt with the testing of esters plus additives to improve lubrication qualities.

Following the recommendations as to the suggested lubricity properties mentioned earlier, the evaluation of extreme pressure (E.P.) and anti-wear additives in ester formulations was begun. A total of fourteen different E.P. type additives were investigated. These additives can be generally grouped into three classes, those compounds containing both sulfur and chlorine, those with sulfur and those with sulfur and phosphorus. Materials containing phosphorus such as tricresyl phosphate are a fourth class and may be considered to be anti-wear agents rather than E.P. compounds.

Suggested weight percentages of E.P. additives for use in finished formulations varied from about 3.0 to 10. In general, studies were carried out at 5.0 weight percent additive concentration. In most cases little was gained by using more than 5.0 weight percent of an E.P. additive. Table III lists the compositions of some E.P. containing experimental lubricants that were tested. The wear characteristics of experimental gear lubricants when tested in the Shell Four-Ball Wear Tester are shown in Table IV.

The Shell Four-Ball Extreme Pressure Tester was in turn used for evaluating the high load range and thereby pointing out the E.P. effect of additives. Runs were made, starting at 40 Kg. loads, and increased by 20 and 40 Kg. increments until permanent welding resulted. In this work, an approximate load for incipient seizure has been determined graphically. It is the point where a definite seizure with recovery of the steel ballbearings begins. Based on many series of runs, it is estimated that the points of incipient seizure determined do not exceed an error of ± 5 kilograms. The relative effectiveness of E.P. materials in esters as determined in the Shell Four-Ball E.P. Tester is shown in Table V.

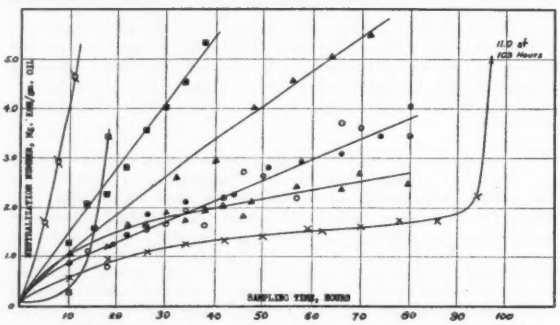


Fig. 2. Oxidation stability of experimental ester-base fluids at 347F. Test Fluids:

@ di-2-ethylhexyl sebacate
× phenothiazine in di-2-ethylhexyl sebacate
□ ditertiarybutyl-paracresol in di-2-ethylhexyl sebacate
△ Composition G
▲ sulfur-chlorine additive, phenothiazine in di-2-ethylhexyl sebacate
O Composition E
● Composition F
Specification type MIL-O-6086, medium grade

All of th sulfur-chlorine containing additives tested showed similarities. These additives as a class aid the base stock little in producing low wear in the wear tester in the low load range. However, in the E.P. tester the wear rate at the initial 40 kilogram load was relatively low as shown in Table V. Points of incipient seizure and permanent weld are much increased by the addition of this class of compounds. The use of more than 5.0 weight percent of the material, however, shows little improvement in the points of incipient seizure and permanent weld.

Of the sulfurized additives tested, all appear to be about the same at the point of incipient seizure with a slightly better point of permanent weld than the sulfur-chlorine materials.

TABLE I
SOME PROPERTIES OF ESTERS

ESTER	MOLECULAR WT.	CENTISTOKE VISCOSITY AT 210F	100F	—40F	V. I.	M. P. °F	FLASH POINT °F
Di-2-Methylbutyl Succinate	258	1.42	4.12	226	82	[1]	320
Di-2-Ethylhexyl Succinate	342	2.10	7.00	1,059	107	—70	325
Di-2-Ethylhexyl Maleate	340	2.24	9.26	2,930		[1]	365
Di-Isobutyl Adipate	258	1.46	4.00		111	0	
Di-Sec-Amyl Adipate	286		4.48	246		[1]	
Di-2-Ethylhexyl Adipate	370	2.35	8.11	798	118	—80	375
Di-Isooctyl Adipate	370	2.80	9.99	1,040	141		410
Di-Sec-Amyl Azelate	328		6.48	417		[1]	365
Di-2-Ethylhexyl Azelate	412	3.01	11.10	1,164	144	[1]	415
Di-Butyl Sebacate	314	2.10	6.10		155	+25	385
Di-Sec-Butyl Sebacate	314		6.21	308		—50	350
Di-Sec-Amyl Sebacate	342	2.27	7.48	528	127		375
Di-2-Ethylbutyl Sebacate	370	2.70	9.10		152	—10	385
Di-2-Ethylhexyl Sebacate	426	3.28	12.30	1,400	155	—55	440
Di-2-Ethylhexyl Phthalate	390	4.26	29.7		7	[1]	385
Polyethylene Glycol Di-2-Ethyylhexanoate		2.82	11.0		113	[1]	

[1]No Crystallization observed after storage for 60 days at —100F.

The third class of E.P. additives, the thiophosphates, when tested all showed approximately the same wear and E.P. characteristics. They showed little improvement over non-additive fluids in the point of permanent welding.

In general, the improvement in the point of seizure is about equal for all three classes of E.P. compounds. The sulfurized and sulfur-chlorine containing additives, however, impart higher points of permanent welding.

TABLE II

WEAR CHARACTERISTICS OF VARIOUS DIESTERS

Test Apparatus: Shell Four-Ball Wear Tester, SKF Industries Grade No. 1 (0.5 in. diameter) Steel Ballbearings

TEST FLUID	AVERAGE WEAR SCAR DIAMETER, MM STEEL-ON-STEEL BEARING SURFACES 1 Kg.	10 Kg.	40 Kg.
Di-2-Ethylhexyl Maleate	0.23	0.56	0.84
Di-2-Ethylhexyl Adipate	0.32	0.64	0.84
Di-Isooctyl Adipate	0.15	0.65	0.91
Di-2-Ethylhexyl Azelate	0.39	0.63	0.79
Di-Sec-Amyl Sebacate	0.30	0.63	0.84
Di-2-EthylHexyl Sebacate	0.26	0.55	0.69
Di-2-Ethylhexyl Phthalate	0.30	0.51	0.72
Polyethylene Glycol-2-Ethylhexanoate	0.35	0.62	0.97

III. OXIDATION AND CORROSION STABILITY STUDIES

The oxidation and corrosion stability of synthetic esters and ester-base fluids is of prime importance in the development of new lubricants for use in current and proposed service equipment. Without favorable stability toward oxidation and corrosion under the conditions prevailing in service equipment, the synthetic esters cannot compete with available hydrocarbon-base lubricants.

To justify the widespread use of ester lubricants they should be clearly superior in most physical properties enabling them to overbalance their high cost limitation relative to hydrocarbon products. Without inhibitors the chain and phthalate type dibasic acid esters are very poor replacements, indeed, for hydrocarbon oils. This is offset by the better solvent action exhibited by most esters which allows for the possible use of a broader field of inhibitor types. Fortunately, the use of inhibitors in esters has resulted in greatly increased stability under oxidation and corrosion test conditions. Phenothiazine[7] and ditertiarybutyl-paracresol[4] have proved to be efficient oxidation inhibitors even in small concentrations in ester formulations.

Three oxidation and corrosion tests were used in the evaluating the ester base lubricants containing various anti-wear and extreme pressure additives. The test consists essentially of passing 10 liters of air per hour through 100 ml. of test fluid maintained at a desired temperature for a specified period of time. In one case the temperature was held constant at 250F. for 168 hours. The temperature was maintained at 347F. for from 30 hours to the stable life of the fluid in the second case. To act as oxidation catalysts, metal test specimens of copper, steel, magnesium, aluminum, and cadmium-plated steel are placed in the test liquid during the test.

The third type of oxidation and corrosion test used was the Thin-Film Oxidation and Silver Corrosion Test. Due to the manner in which some turbine bearings are lubricated, the thin-film oxidative-type tests were made a part of the development program in an attempt to simulate conditions that exist in the turbo-prop engine. The apparatus used was that previously developed by the Petroleum Refining Laboratory, Pennsylvania State College and used for oxidation and corrosion testing of instrument oils. Being a thin-film, high-catalyst-area type of test it appeared to be suitable for reproducing thin-film oxidation and corrosion similar to that noted in the turbo-prop engine.

TABLE IV

WEAR CHARACTERISTICS OF EXPERIMENTAL GEAR BOX LUBRICANTS

Test Apparatus: Shell Four-Ball Wear Tester, SKF Industries Grade No. 1 (0.5 in. diameter) Steel Ballbearings

TEST FLUID COMPOSITION NUMBER	AVERAGE WEAR SCAR DIAMETER, MM STEEL-ON-STEEL BEARING SURFACES 1 Kg.	10 Kg.	40 Kg.
A	0.32	0.42	0.51
B	0.26	0.55	0.60
C	0.25	0.54	0.69
D	0.16	0.26	0.36
E	0.24	0.59	0.75
F	0.29	0.35	0.47
G	0.37	0.48	0.72
H	0.19	0.42	0.46
I	0.25	0.40	0.44
J	0.16	0.28	0.67
K	0.28	0.40	0.64
L	0.15	0.28	0.39
M	0.16	0.23	0.37
N	0.16	0.25	0.42
O	0.14	0.25	0.44
Q	0.13	0.22	0.38

The apparatus is shown in Figure 1. It consists of a specially designed, solenoid-operated, bucket-type lift pump; a large pyrex test tube; steel jack chain catalyst plus a section of a silver-plated steel aircraft bearing; an air inlet tube; and a water cooled condenser. The test procedure calls for a seven inch packed height (approximately 2000 cm^2) of steel jack chain in the tube with the silver-plated steel bearing in the middle of the chain packing to insure maximum steel-on-silver contact. Fifty grams of test oil are added and the assembled apparatus is placed in a constant temperature bath at 347F. The test oil is pumped at a rate of about 175 ml./min. up through stainless steel tubing to a point above the chain. There the oil leaves the tubing and flows by gravity down over the catalyst and is continuously recycled. Simultaneously, air at a rate of 10 liters/hour flows up through the packings countercurrent to the oil flow[4]. A test period of 20 hours was used in this work.

(Continued on page 197)

TABLE III

COMPOSITIONS OF EXPERIMENTAL GEAR BOX LUBRICANTS

COMPONENT	COMPOSITION A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Di-2-ethylhexyl sebacate		100	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
High molecular wt. V.I. improver			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Organophosphate				X		X										3.0	5.0
Phenothiazine					X	X	X						X	X	X	X	X
Sulfur-chlorine extreme pressure additive					X	X											
A dithiophosphate containing zinc													X				
Sulfur-chlorine extreme pressure additive							X										
A sulfurized hydrocarbon								X									
A sulfurized hydrocarbon									X								
Mercaptobenzothiazole									X								
Sulfurized sperm oil										X							
Triphenylthio phosphate														X			
Triphenyltetrathio phosphate															X		
Sulfur-chlorine lard oil											X						
A dithiophosphate containing zinc												X					
Specification type MIL-O-6086, Grade M*	100																

*A petroleum base gear oil containing a sulfur-chlorine type additive

LUBRICATION AND THE LOAD-CARRYING CAPACITY OF GEARS*

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ABSTRACT: A large share of the world's power passes, at some stage, through the bottleneck of a gear-tooth contact. The problem of determining the power-transmitting ability (or load-carrying capacity) of gears is therefore one of considerable importance. It is not difficult if thought of in simple terms and as limited solely by the risk of tooth fracture, since gear teeth are machine elements and subject to the well-understood laws of mechanics. But the oil film separating the teeth is a machine element too, though seldom thought of as such, and gears can fail otherwise than by tooth fracture in ways which can be influenced by the character of the oil and its interaction with the conditions under which it is used. The functions of the oil supply are therefore reviewed in relation to the recognized types of gear failure and the oil shown to be much more than a mere lubricant in the exact sense of the word. Ways in which operating conditions and choice of lubricating oil can influence the scoring and pitting of gears in service are considered and some research findings concerning the influence of oil properties and other factors are discussed. Can we predict gear and gear-oil performance from such data? Not yet, perhaps, but the present outlook affords hope that this may one day be a practical possibility. The problem is still far from being satisfactorily solved, however.

INTRODUCTION

The function of a toothed gear is the positive transmission of motion from one shaft to another, generally with some alteration in speed and frequently with very great power. A gear can be made to perform its task well enough so long as the power transmitted is unimportant, as in a clock for example, but when the successful transmission of massive horsepower is the prime consideration it is not so well adapted to its task. Only one or two of its many teeth are in action at any moment. The shape of the teeth, moreover, is necessarily such that at a given instant a very small area must bear the entire transmitted load. Furthermore the current trend in machine design is towards smaller and lighter units incorporating smaller and more-heavily loaded gears. This means that ways must be found of safely passing more power than ever before through the dwindling tooth contact, in other words of increasing its load carrying capacity.

STRONGER GEARS?

When the load-carrying capacity of the toothed gear first attracted attention many years ago its determination was treated as a simple problem in mechanics and the solution embodied in the familiar "Lewis" formula. This treated the tooth as a loaded cantilever and by ignoring such complicating factors as the influence of fillet curves at the roots yielded a working tooth-load based on freedom from the risk of gross breakage. Later the Lewis formula was modified in recognition of the fact that speed as well as load was a factor in the failure of gears but essentially it remained concerned with the problem of avoiding tooth fracture due to crude overload and fatigue, ignoring the possibility of failure by deterioration of the working surfaces through scoring, pitting, excessive wear, or other of the causes identified and illustrated by the American Gear Manufacturer's Association[1]. In all these forms of failure, any one of which can write off a gear as effectively as if it had lost one or more of its teeth, it is immediately evident that the part played by the lubricant can no longer be overlooked. Nevertheless there remain ways in which the load-carrying capacity of conventional gears can be enhanced through modifications in design and methods of manufacture. The change from spiral-bevel to hypoid gears, in automotvie rear axles, is an example of a change in design which resulted in inherently stronger tooth forms—though incidentally imposing on the lubricant, through the severity of the sliding motion involved, the extreme conditions which led to the development of E.P. oils.

Another refinement which has been practiced for some years, is that known as "tip relief" or "profile modification"[3]. This consists of paring away parts of the rubbing faces of the gear teeth to allow for the slight lead which they gain due to the deflection of the one or two teeth under load. If not so modified the teeth coming into mesh would engage with a clash instead of sliding smoothly on to one another, and this could lead to premature scoring.

Yet another change favored by some and intended to reduce the risk of pitting is that to the so-called "all addendum" gear, in which the teeth of the pinion are located wholly outside the pitch cylinder and those of the wheel wholly within (the wheel thereby becoming "all-dedendum"). Pitting is usually confined to the dedendum of the pinion teeth and has been explained[2] as a joint effect of the negative specific sliding which occurs on the flanks of the teeth and this greater number of stress repetitions to which the pinion is subjected compared with the wheel. With spur gears it occurs at the point where one-pair contact begins, and there is a consequent sudden increase in stress. By the expedient of making the pinion teeth "all addendum" this danger zone is removed from the sphere of action. With helical gears the reduction of surface stress is probably an important factor. Maximum sliding velocities are higher with all-addendum teeth, and the risk of scoring correspondingly increased.

Among modifications in methods of manufacture, shot peening has been found[4] to increase the resistance of gear teeth to failure by fatigue, probably because of the relief it affords to surface stresses set up during manufacture.

Resistance to wear is a highly desirable property of gear teeth and, in a sense, a contribution to strength. When shock-loading and chatter are the principal causes of tooth wear, E.P. additives have been found[5] relatively ineffective in combating it; indeed it is well known that the more-active E.P. additives can be fully effective only by chemical reaction with the rubbing surface—the possibility of a slightly increased rate of wear having to be accepted as less un-

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desirable than the risk of seizure. In these circumstances an oil of higher viscosity must be used, to cushion the load. Under milder conditions so-called "anti-wear" additives can be effective but perhaps the possibilities of obtaining increased wear resistance through improvements of a metallurgical character in the material of the gear teeth have not yet been completely exhausted. For example, it has been suggested recently[6] that the importance of mere hardness as a factor in wear resistance has been over emphasized and that some mechanical properties of metals related to the melting point may greatly influence wear.

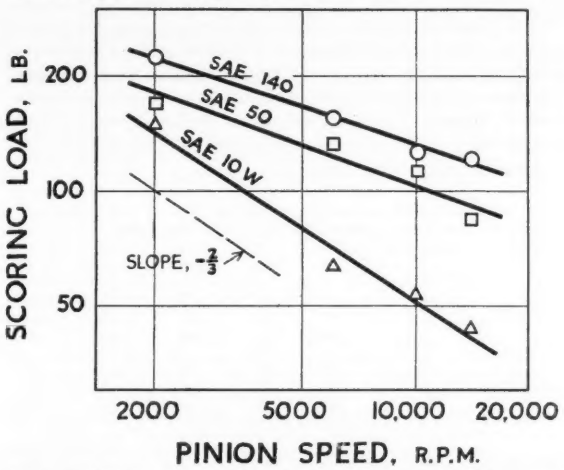

Fig. 1 Scoring tests on a high-speed gear rig—Influence of pinion speed on load-carrying capacity. The scoring load of spur gears lubricated with straight mineral oil has been shown[12], with the aid of Blok's expression for the "temperature flash" between sliding contacts, to vary theoretically as the —⅔ power of the pinion speed. The graph shows this to be true for the light oil, but with the heavier oils there is evidently another influence at work raising the scoring load at the higher speeds, which may well be an increasing proportion of hydrodynamic lubrication. This graph was derived from the data of Table 3 by ignoring the influence of temperature (which was shown to be non-significant).

GEAR FAILURE AND THE LUBRICANT

It is common to think of the lubricant, in gear-tooth engagement, as performing a variety of functions such as reducing friction, carrying away frictional heat, preventing seizure, retarding wear, and the like, and to recognize that it does most of these things by being sufficiently viscous to prevent the metal surfaces of the mating teeth coming into direct contact. It is less usual, however, for it to be thought of as an essential element of the machine—through which the load must be transmitted—and deserving to be designed into the machine from the start, though a welcome reorientation of thought in this direction has begun[7, 8].

Obviously the lubricant can have little or no direct influence on tooth breakage, and it is quite properly ignored in the Lewis formula. True, a valiant attempt has been made recently[9] to incorporate oil viscosity into this formula by ingeniously taking advantage of the form in which the allowance for speed was introduced by Barth, and the predictions of the modified equation do show a measure of correlation with some limited experimental results. Although the theoretical justification for such a step has not been pressed and the ultimate solution of the gear-performance problem may prove to involve other factors, nevertheless a useful practical contribution has in the meantime been made.

The pitting of the tooth faces is another form of failure upon which it might be supposed the lubricant could have little or no influence, since the dependence of pitting on the magnitude of the surface stress and the number of stress repetitions identifies it as a manifestation of fatigue, the liability to which is wholly a property of the metal. Nevertheless there is evidence that the character of the lubricating oil is not without influence in postponing or accelerating the onset of pitting in gears. Pits are thought to be formed by the spreading of internal shear cracks, which are imagined to develop below the surface (in the zone where the maximum stress theoretically occurs) and to spread slantwise until they reach the surface. Here they may be rapidly opened up by the hydraulic action of a sufficiently penetrating lubricating oil. Equally, of course, minute surface cracks left by machining operations or caused by surface stresses may be extended into the metal by similar action. The same shot-peening process that has been recommended[4] for enhancing the fatigue resistance of gear teeth may also very likely increase their resistance to pitting, by effectively sealing the minute surface cracks which if left open could form the starting points of pits. Experiments have shown[10, 11] that oils containing powerful E.P. additives, designed to form films on

Viscosity grade	Additive in base oil	Viscosity at supply temperature cS	Number of stress repetitions before pitting of bronze disc began, millions	Mean
SAE 5W	None	5.5	1.35 0.77 1.40	1.17
SAE 50	None	55	2.70 4.05 3.02	3.26
SAE 50	10% proprietary sulphur/chlorine E.P. additive	49	0.72 0.54 1.58 2.12	1.24
SAE 50	10% sulphurized fat	55	0.59 0.77 1.22	0.86

Table 1—Results of fatigue tests on a disc machine. A steel and a bronze disc were rotated with their cylindrical surfaces in contact and moving at different speeds in opposite directions—under a load of 725 lb. per inch—thus simulating to some extent the severest conditions of worm-gear engagement. There was a copious supply of oil at 158F. It will be seen that a heavy oil gave much better protection against pitting of the bronze disc than a light oil and that the addition of sulphur-containing materials to the heavy oil drastically reduced the fatigue life of the bronze discs lubricated with it.

the rubbing surfaces by chemical attack, notably accelerate the onset of pitting (see Tables 1 and 2). This may be by etching minute corrosion pits which form the starting points of cracks subsequently extended by hydraulic action into the already fissured zone below the surface. It was also concluded, from the same experiments, that the heavier the oil the longer gears will run without pitting. Perhaps this is because the more viscous oil cushions the load more effectively, resulting in a lower peak stress of which many more repetitions are needed to bring about failure by fatigue. Here it would seem that a low-V.I. oil may have certain advantages, at any rate in systems which operate at a fairly constant temperature, because of its greater tendency to become temporarily more viscous, or even to solidify, under high pressure.

IS GEAR LUBRICATION HYDRODYNAMIC?

Complete protection against scoring, abrasion and wear can only be achieved if the gear teeth can be completely separated by an oil film while carrying load. This implies the possibility of full hydrodynamic lubrication, to the maintenance of which the shape of gear teeth—with their convex surfaces—is not very conducive. It has been suggested[9] that lubrication is fully hydrodynamic up to loads only a little below those sufficient to cause scoring and although this view has not yet received general acceptance there is nevertheless experimental evidence for the existence of some

hydrodynamic lubrication between gear teeth. In the graph of load-carrying capacity versus speed (see Fig. 1), whereas with the lightest oil (with which the smallest proportion of hydrodynamic lubrication would be expected) these two quantities are related by an index of $-2/3$, which is the theoretical value derived[12] from thermodynamical considerations assuming purely boundary lubrication; the corresponding indices for the heavier oils are significantly less showing that some relief must have been gained as the speed was increased which could well be attributed to a greater proportion of the load being carried hydrodynamically by the more viscous oils. Possibly most of the load is supported by boundary films while a measure of hydrodynamic lift may be derived either from oil wedges resulting from local elastic deformation of the material of the gear teeth[8], or else perhaps from the trapping of oil within minute shallow recesses in the tooth surfaces and its subsequent expulsion under pressure over the brims of such recesses. Some of the experimental findings relating to this problem appear conflicting at a first examination. When, for example, in some recent work at Thornton, three H.V.I. oils of different viscosities were tested in a gear rig at different temperatures and pinion speeds (see Table 3) it was found that changing to a heavier oil raised the scoring load, as it would be expected to if lubrication were mainly hydrodynamic, whereas increasing the speed *lowered* it, which was the reverse of what it would be expected to do if lubrication were mainly hydrodynamic, and pointed to the conclusion that lubrication

Viscosity grade	Additive in base oil	Viscosity at supply temperature cS	Number of stress repetitions before pitting began, millions	Mean
			0.55—0.65	
			0.61—0.80	
SAE 140	None	90	0.58—0.62	
			0.80—0.89	
			0.65—0.83	
				0.76
			0.29—0.50	
			0.35—0.53	
	8¾% proprietary		1.69—1.74	
SAE 140	sulphur/chlorine	110	0.06—0.24	
	E.P. additive		0.20—0.29	
			0.36—0.56	
				0.65
			>1.98	
			>1.80	
SAE 250	None	140	>1.80	
			0.52—0.60	
			0.91—1.09	
				1.45

Table 2—Results of fatigue tests on a gear rig. A pair of steel spur gears, of 15/16 ratio and nominally 5DP, were operated continuously at 200 rpm under a pitchline loading of 8110 lb. per inch, being stopped daily for inspection until pitting was seen. There was a copious supply of oil at 158F. It will be seen that the addition of an E.P. additive to the lighter oil was not an effective substitute for a simple increase in viscosity grade as a means of postponing the onset of pitting.

was mainly of a boundary character. There is an apparent contrdiction here which, however, disappears if it is assumed that the change to an oil of higher viscosity was beneficial not principally because of any increase in the hydrodynamic factor which it made possible but rather because it meant a change in some other oil property (as yet unidentified but conveniently associated with viscosity grade) and that this was the real reason for the increased scoring load obtained. This assumption is supported by the fact that changing the supply temperature—and thereby the viscosity—of any one of the test oils had no significant influence on its scoring load notwithstanding that the resulting viscosity changes were of the same order as the differences in viscosity between the different oils at a given operating temperature. Evidently changing the fluidity of an oil without changing its composition does not greatly affect its load-carrying capacity—another fact which suggests that the proportion of the load carried hydrodynamically in gear lubrication cannot be very great.

ANOTHER EXPLANATION

The apparent dependence of load-carrying capacity, in given circumstances, on viscosity *grade* rather than operating viscosity is, at first sight, puzzling and has led to the conjecture that it is some other property of the oil, of which viscosity is only a convenient-index, that is the vital factor. It is tempting to infer, as Blok[13] has done, that this property —be it mean molecular weight, volatility, or something more elusive—implies the existence of a critical temperature above which a particular oil can no longer function as a lubricant between given surfaces, and to relate this "Critical Temperature for Failure," as it is coming to be called, to the flash temperature in the contact which can be calculated[14] from thermodynamical principles.

Viscosity grade	Viscosity at supply temperature cS	Supply temperature of oil, °F	Scoring load (lb.) on lever for pinion speed of: r.p.m. 2000	r.p.m. 6000	r.p.m. 10,000	r.p.m. 14,000
	15	140	160	70	55	45
SAE 10W	6.5	194	130	65	65	30
	3.6	248	155	60	45	60
	84	140	160	135	110	95
SAE 50	26	194	165	130	125	100
	11.7	248	180	130	100	60
	170	140	230	160	120	120
SAE 140	47	194	245	165	145	120
	19	248	205	140	120	125

Table 3 Results of scoring tests on a high-speed gear rig. A pair of steel spur gears, of 24/26 ratio and 5DP were operated at a load which was increased at the end of each five-minute spell by 5 lb. on the lever arm of the loading device until scoring of the gear teeth was observed. Statistical analysis confirmed the impressions conveyed by the figures that scoring load was highly dependent on the choice of oil as well as on pinion speed though the response to speed was not the same for every oil. On the other hand no influence could be attributed to the supply temperature of the oil. (The above results can be converted to pitch-line tooth loading in lb. per inch by multiplying them by 21.6). All three oils were fractions of the same HVI solvent-extracted crude.

It must be admitted that there is as yet little direct experimental evidence for the existence of either temperature but the hypothesis is a stimulating one and has already found practical application in elucidating problems of gear lubrication[12]. Its further pursuit seems eminently justifiable.

The action of Extreme Pressure additives is generally agreed to consist of the deposition as required of films of low shear strength on the rubbing surfaces of the gear teeth, preferably only under the influence of the high temperature engendered by frictional heat. Their effectiveness in enhancing load-carrying capacity may be expressed in terms of the Critical-Temperature hypothesis by stating that the new system of oil and rubbing surfaces which they bring into being possesses a higher Critical Temperature for Failure than the original one and will therefore permit the Flash Temperature[14] in the contact to be raised—either by increasing the load on the gears or raising their speed. The enhanced Critical Temperature for failure may not be due solely to the altered character of the rubbing surfaces resulting from the action of the E.P. additive but also in part to a change in some relevant though unidentified property of the oil, brought about by the mere presence in it of the additive. If so this would open up the prospect of a new type of lubricating-oil additive the action of which would be solely on the oil—by raising its Critical Temperature for Failure in the presence of most rubbing surfaces—rather than almost wholly on the rubbing surfaces themselves (which are thereby exposed to the risk of excessive "wear" by chemical attack).

(Continued on page 201)

OIL FOG LUBRICATION*

by D. G. Faust
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Mr. Faust graduated from Lehigh University in 1934 as an Electrical Engineer. After several years as an Industrial Engineer, including one year in this capacity with the Walter Kidde & Co., Inc., he took over the responsibilities of Chief Project and Test Engineer for the W. K. Co., dealing with the design, testing, and application of equipment for the utilization and application of high pressure gases. In 1949 he joined the C. A. Norgren Co. as Chief Engineer in charge of all product design and development.

ABSTRACT: Growing from infancy during the past 25 years, oil fog lubrication is today a vital and indispensable component of this country's industrial machine.

A great deal of research stands behind the present day micro-fog lubricators. It seems obvious that an understanding of the behavior of lubricating aerosols, particularly the wetting or lubricating characteristics, is essential, if any great degree of progress is to be made in this field of lubrication. Research into the behavior of lubricating aerosols was started in 1945. Progress was slow. New techniques and equipment were required to produce and analyze oil fog of extremely small particle size. The purpose of this paper is to present a discussion of some of the highlights of this research program, including a description of some of the techniques used along with pictures and diagrams of some of the apparatus developed for this purpose.

The utilization of oil fog lubrication is being extended daily. Applications previously considered impractical are now an accomplished fact.

Growing from infancy during the past 25 years, oil-fog lubrication is today a vital and indispensable component of this country's industrial machine.

A great deal of fundamental research stands behind the present day micro-fog lubricator. It was essential, in order to make any great degree of progress in the field of oil-fog lubrication, that a thorough understanding of the behavior of lubricating aerosols be at the disposal of those responsible for the design of this type equipment, and for the application of this equipment to existing problems. With this though in mind, the C. A. Norgren Company, in 1945, initiated a research program aimed at determining some of the basic fundamentals governing the behavior of lubricating aerosols and establishing a sound basis for the future application of oil-fog lubrication. After five to six years of research in this field, we are fully cognizant of the fact that aerosol lubrication is only an infant, and that the possibilities in this endeavor are limitless. It should be clearly understood that aerosol lubrication is not a "cure-all." However, it has solved many difficult industrial lubrication problems, and with increased "know-how," the satisfactory solution to many more problems is within our grasp.

At the outset of the program, it was recognized that the individual particle size of the lubricating aerosol, or oil fog, was undoubtedly the key to the successful development and application of this type of lubrication. We knew, and it was well recognized by many others, that large oil-fog particles approaching the size of droplets would readily wet or lubricate a bearing or other surface. We also knew that very finely divided oil fog would float around in the atmosphere like so much smoke, and have negligible lubricating value. The problem, therefore, was to find a suitable compromise.

Somewhere within the range of practicability we hoped to find an oil fog of suitable particle size which was fine enough to permit transmission through piping systems without substantial loss by reclassification or condensation, and, at the same time have a fog of large enough particle size, that when applied to a bearing or surface requiring lubrication, it would readily wet such surfaces and provide the desired lubricating medium.

In order to carry out such research, a means of producing an aerosol of consistently uniform quality in respect to particle size over a reasonably wide range of sizes was of paramount importance. Likewise, a measuring device to determine accurately the particle size of the aerosols under study, as well as the necessary apparatus to permit measurement of the wetting or lubricating characteristics of the aerosol under study, were necessary tools before the investigation could be started.

It was deemed advisable to attempt this study using "mono-disperse aerosols," that is, a dispersion of oil droplets of uniform size in air. It was recognized that an aerosol or oil-fog lubricator would produce only a "heter-disperse" fog; therefore, it was necessary to make the basic assumption that each different sized particle of a heter-disperse aerosol would behave independently of the others, and have the same wetting properties as a mono-disperse aerosol of its particular particle size. Fig. 1 shows diagrammatically the components of the generator devised and used for the production of mono-disperse aerosols. It consists of a boiler and reheater, both enclosed in insulated compartments. The aerosol-forming liquid is placed in the boiler; for our investigation, we used n-Hexadecane (cetane) as the aerosol-forming liquid. The boiler is heated electrically, and its temperature is accurately controlled. Filtered air is introduced into the boiler after first passing through an ionizer, consisting of a plug of sodium chloride and a nichrome coil. The current passing through the nichrome coil is accurately controlled by means of a constant voltage transformer. Air passing through the ionizer acts as a carrier for the condensation nucleii, directing them into the upper part of the boiler where they are mixed with the vapour of the substance being heated. This mixture is then passed into the reheater through two fine jets. The relatively high velocity flow through these two jets produces the required turbulence for intimate mixing within the reheater.

The temperature of the reheater is held constant by means of a Variac control, and is maintained at a temperature somewhat higher than that of the boiler. To assist in the formation of a fog, filtered air is bubbled through the aerosol-forming liquid (cetane) within the boiler. In order to avoid destroying the uniformity of the particle size by coagulation, the aerosol, upon leaving the reheater, is diluted approximately 60 per cent with dry, filtered air.

With this apparatus, it was possible to produce a mono-disperse aerosol ranging in particle size from approximately 1/10 micron diameter to the maximum size in which we are interested, approximately 10 micron diameter. The desired particle size could be obtained by adjusting the boiler

* Paper presented at 7th Annual Meeting, ASLE, Cleveland, April 8, 1952

temperature, or the ratio of the air flow through the liquid relative to that through the ionizer, or, by decreasing the rate of ionization. This mono-disperse aerosol generator has served us well throughout our entire investigation, and is still in operation. At the present time, we are planning to build a second mono-disperse generator to assist us in the continuation of this work.

Fig. 2 is a photograph of the "Owl." The code name "Owl" was assigned to the instrument used for the measurement of the aerosol particle size. It consists of a cylindrical chamber, the inside of which is blackened, and a light source. The light source is a Bausch and Lomb Nichols illuminator which can be rotated while observing the aerosol through a low-powered microscope. The axis of rotation is perpendicular to the plane of observation. A cylindrical window in the side of the chamber allows observations at angles from 15° to 165°. These angles are read from a graduated scale. A parallel beam of light directed across the chamber diametrically enters a metal tube which serves as a light trap. The eye piece of the microscope contains a split-field polaroid-disc of which one-half has its vibration direction perpendicular to the dividing line, and the other half has its vibration direction parallel to the dividing line. As the light source is rotated, the scattered light can be observed with the half-field which is polarized parallel to the plane of observation.

The passage of a parallel beam of white light through the aerosol results in an exhibition of what is termed "The higher order Tyndall Spectrum." The number of red bands

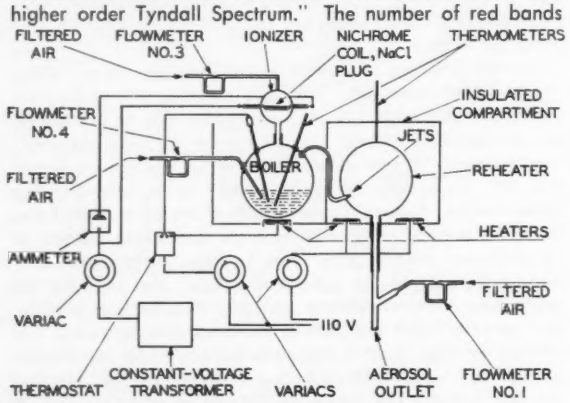

Fig. 1 Mono-disperse aerosol generator

observed has been used to define the order. The brightness of the spectrum increases with uniformity in particle size. The number of times the spectral series is repeated increases with particle radius. The aerosol is viewed through the microscope, and the particle radius may be estimated by counting the number of times the red band appears upon rotation of the microscope. The radius of the particle in microns is approximately equal to 1/10 the number of red bands observed. Once the relationship between the particle radius, or diameter, and the angular position of the red bands has been determined, the measurement of particle size of mono-disperse aerosols becomes quite simple. The red bands are located, and the angle of location is read upon the graduated scale. The radius is then read directly from a graph. Fig. 3 is the graph resulting from the calibration of the "Owl" using n-Hexadecane.

For aerosols having a particle size greater than approximately 1 micron radius, the optical method for determining particle size was not too satisfactory. The frequency with which the spectrum repeated itself confused the readings, and the intensity of the light scattered in the neighborhood of 90° was so low as to make determination impractical. Therefore, for the larger particle sizes, a technique generally referred to as the "Sedimentation Rate" was utilized.

The "Sedimentation Rate" of fog measurements were carried out by passing the aerosol into a 4" diameter glass cylinder which was maintained at a constant temperature by immersion in a temperature controlled water bath. (See Fig. 4). As the settling proceeded, the position of the top of the fog was measured between a 3 centimeter distance as a function of time. The sedimentation was observed in a darkened room with the aid of a bright parallel beam of light. Measurements were not started until the fog had settled approximately 5 centimeters. After settling this distance, convection had practically ceased, and accurate readings could be obtained.

Fig. 2 "Owl"—instrument used for the measurement of the aerosol particle size

Reasonable correlation of particle size determination was obtained between the sedimentation technique and the optical technique in the overlapping regions.

The radius of the particle was calculated from the Stokes-Cunningham equation, $V = \frac{2r^2Sg}{9n}\left[1 + \frac{KL}{r}\right]$

V = Velocity (centimeters per second)
R = Radius of particle
S = Density of particle—density of the air
G = Acceleration of gravity
N = Viscosity of air
K = Constant = 0.9
L = Length of mean free path of air molecules

With the aforementioned apparatus at our disposal, we launched upon a program to determine the wetting characteristics of the aerosol, the effect of particle size, and velocity of impingement upon the wettability of the fog. This was accomplished by dischaging the fog through a jet at

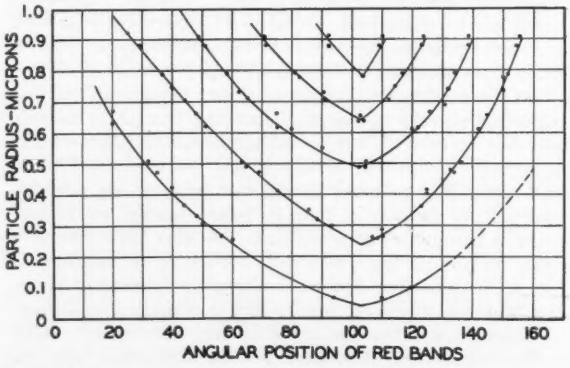

Fig. 3 Calibration curves for the "Owl" using n-Hexadecane

a known velocity, and impinging it upon a 2"x2" piece of foil. Both the particle size and velocity of impingement were varied, and the wetting characteristics of the fog were determined by observation and by weighing the foil before and after exposure to the jet of fog. It was from this accumulation of data that we were able to establish the relationship between aerosol particle size and velocity of impingement required for good surface wetting or lubrication. A chart showing this relationship appeared in an article by this author entitled "Wetting Characteristics of Lubricating Aerosols," published in *Product Engineering*, July, 1951, Vol. 22, No. 7, page 131, and is reproduced here as Fig. 5.

In brief, this shart shows that as the individual oil particle becomes infinitesimal in size, the velocity required to achieve wetting or lubrication becomes infinite. Going in the other direction, it can be seen that, as the oil particle gets larger, the critical wetting velocity becomes lower. This phenomenon is quite understandable, and is readily accepted.

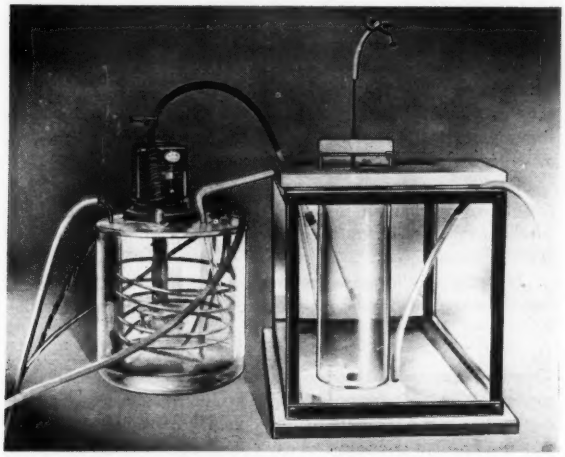

Fig. 4 Equipment used in determining "Sedimentation Rate" of fog measurements

One purpose of this phase of the investigation was to obtain some quantitative results which would assist us in selecting a satisfactory operating range. Obviously, any choice had to be a compromise.

It was desirable to produce an oil fog of very small particle size so that it could be transmitted through piping systems, without danger of condensation in the conveying piping. On the other hand, the individual particle size must be large enough so that when the fog reached its point of application, it could be utilized as a lubricating medium. If the particle size were too small at this point, it would be impossible to achieve velocities high enough to cause the individual oil particles to wet. Therefore, such a fog would be useless.

Our next step was to analyze the oil fog produced by various designs of micro-fog lubricators and determine whether or not we were producing an oil fog having suitable characteristics to achieve our purpose. To carry out this phase of the program, we constructed the "Cascade Impactor" shown in Fig. 6.

The Cascade Impactor consists of a series of jets of decreasing size with a sampling slide mounted close behind each jet. The aerosol stream enters the Cascade Impactor at the top and passes downward through a series of jets at increasing rates up to approximately sonic velocities and deposits the largest particles on the first slide, and the successively smaller particles on the subsequent slides. This particle size fractionation was used to speed the tedious process of determining the size distribution from chemical or colorimetric analysis of the amount of material collected on each slide.

For the purposes of this analysis, aerosol having sizes ranging from .4 to 1.6 microns diameter were chosen, and it was believed that this range would cover the bulk of the sizes produced by mirco-fog lubricator. In particular, six different particle size diameters were selected; .4, .6, .8, 1.0, 1.2 and 1.6 microns. The deposition of these aerosols were studied, using six jets having diameters of 1.48, 1.69, 1.90, 2.15, 2.48 and 2.80 millimeters, and the mono-disperse fog generator as the source of the aerosol.

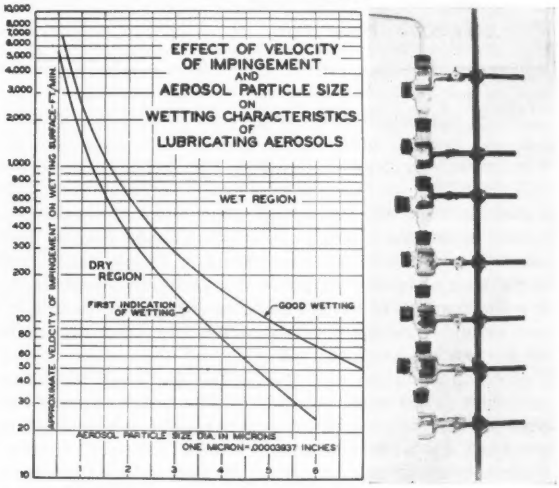
EFFECT OF VELOCITY OF IMPINGEMENT AND AEROSOL PARTICLE SIZE ON WETTING CHARACTERISTICS OF LUBRICATING AEROSOLS
APPROXIMATE VELOCITY OF IMPINGEMENT ON WETTING SURFACE-FT/MIN
WET REGION
DRY REGION
FIRST INDICATION OF WETTING
GOOD WETTING
AEROSOL PARTICLE SIZE DIA IN MICRONS
ONE MICRON=.00003937 INCHES

Fig. 5 Effect of velocity of impingement and aerosol particle size on wetting characteristics of lubricating aerosols
Fig. 6 The Cascade Impactor

It can be seen that for each particle size, six deposition values in the form of the percentage of aerosol deposited could be obtained from each jet. With the conditions of flow remaining constant, there would be developed a series of deposition values for each particle size and each jet, the total result being six sets of deposition values, one set for each jet. It may be seen that these deposition values could

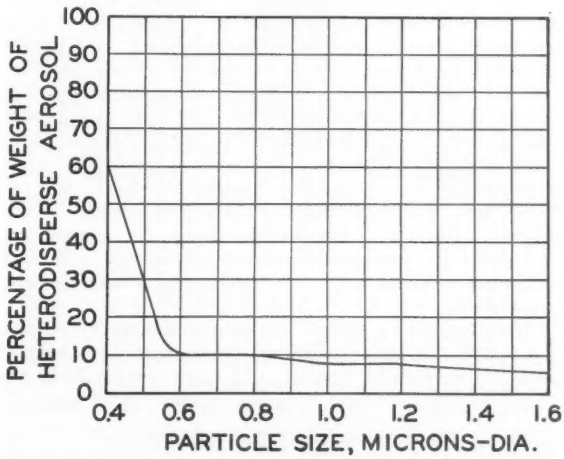

Fig. 7 Particle size distribution micro-fog lubricator

be applied to the particles of the heter-disperse aerosol. By measuring the amount of heter-disperse aerosol deposited from a particular jet, the deposition values for that jet could be set in the form of an equation stating that the summation of the fractions of each particle size deposited must equal the total deposit of the heter-disperse aerosol. By taking

(Continued on page 203)

FRETTING CORROSION*

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Mr. Barnett received his Sc.M. Degree in organic chemistry from New York University in 1931 and joined the Texas Co., Beacon Laboratories staff, later that year. During the past 20 years he has devoted considerable time to man problems of industry which have some association with lubrication.

Generally speaking, fretting corrosion is a surface damage caused when two pieces of solids are rubbed against each other long enough. This phenomenon is usually recognized in the case of ferrous metals by the formation of red Fe_2O_3. It is the purpose of this article to briefly review the subject, and to discuss recent developments in the field. An earlier review was presented in 1948[1].

Fretting corrosion also goes under the name of friction oxidation as will be discussed later. This happening has also been called "false brinelling" because the pits or cavities produced by fretting corrosion on the raceways of antifriction bearings are similar in appearance to the Brinell marks produced by stress deformation.

The mechanism of fretting corrosion has been incompletely understood as compared to what happens in other forms of metal damage. There has been ignorance of: one; just how fretting occurs, and two; how to stop it. Based largely on recent work done by the national Advisory Committee of Aeronautics, we now have a far more conclusive picture of how fretting occurs. However, the mitigation of this happening is still far from satisfactory, and no way has been found to completely prevent it.

Fretting corrosion is most apt to happen when vibratory and/or oscillatory motion is present; where there is no chance to maintain a hydrodynamic layer or to sustain a boundary layer between the two bearing surfaces.

With very clean surfaces, fretting can occur at very low speeds and with motion in one direction only. In this connection, a quotation[2] from Leonardo DaVinci appears especially pertinent "all things and everything whatsoever, however thin it may be, which is interposed in the middle between objects that rub together lighten the difficulty of this friction." The reason that fretting corrosion is so prevalent in industry and transportation is that relative motion of small amplitude between parts of machinery is a very common occurrence.

As discussed by Almen[3] fretting is serious for the following reasons: 1. Makes machine parts susceptible to fatigue. 2. Ruins dimensional accuracy. 3. Ruins surface finish. 4. Jams bearing clearances through accumulation of debris.

EXAMPLES OF FRETTING CORROSION

Fretting is particularly prevalent in the aircraft field because of the vibration of these flying machines, particularly when reciprocating engines are used. The increased use of helicopters has brought this condition very much in the forefront because the vibration of control mechanisms in the present stage of helicopter development has been a serious problem as will be discussed further in this paper.

* Paper presented at a meeting of the ASLE Milwaukee Section, April 23, 1951

DETECTION OF FRETTING CORROSION

In a large industrial organization such as the Beacon Laboratories of The Texas Company, the examination of used machine parts and bearings is an important segment of the work. In these cases, it is quite important to be able to differentiate among the various forms of metal damage which may have occurred. One of the most difficult distinctions to make is that between common rust and fretting corrosions products because of the identification of the latter with red iron oxide (Fe_2O_3) which is similar in appearance to the hydrated iron oxide of common rust.

The following section on the detection of fretting corrosion will be limited to the most common example which is also the most important one, namely the fretting corrosion of ferrous metals.

In order to diagnose fretting corrosion, a brief review of the chemistry of pertinent iron oxides appears to be in order.

Forms of Iron Oxides

Crystal Form	Name	Color	Remarks
alpha Fe_2O_3	Hematite	Red	Non-magnetic
alpha $Fe_2O_3.H_2O$	Goethite	Reddish	Non-magnetic
gamma Fe_2O_3	Maghamite	Reddish	Magnetic

Fortunately for the analytical chemist, the foregoing three forms of iron oxide have different x-ray diffraction patterns; such patterns are the best way to identify these closely similar compounds.

Reactions

Unfortunately the foregoing iron oxides are not stable in the presence of heat as shown by the following reactions:

A. alpha $Fe_2O_3.H_2O \xrightarrow{150\text{-}200^\circ F.}$ gamma $Fe_2O_3 + H_2O$

B. gamma $Fe_2O_3 \xrightarrow{600\text{-}800^\circ F.}$ alpha Fe_2O_3

This complicates both the analysis and the diagnosis of what has happened on machine parts in the field. These reactions are usually incomplete as would be expected: that is, mixtures of alpha $Fe_2O_3.H_2O$, gamma Fe_2O_3 and alpha Fe_2O_3 may all be found together.

Diagnosis

This problem is frequently over-simplified by stating that hydrated oxides are a proof of ordinary rusting and that finding alpha Fe_2O_3 proves that fretting has occurred. Conclusive proof is not that simple.

If alpha $Fe_2O_3.H_2O$ is found, then probably rusting has occurred, with no fretting corrosion. If gamma Fe_2O_3 is found, then the metal probably experienced rusting only, as the gamma form is not a direct iron + oxygen oxidation product. Specifically, the gamma form is brought about by heating alpha $Fe_2O_3.H_2O$ as shown in the foregoing reactions.

If the alpha Fe_2O_3 form is found, then a variety of choices are presented to the analyst: 1. the debris may all be due to fretting corrosion; 2. the oxide may be rust which had been severely heated later on to form the dehydrated alpha form; or 3. the alpha Fe_2O_3 may have come from both causes happening concurrently or successively.

The foregoing illustrates why all conditions must be examined to arrive at a reasonable decision as to whether fretting has occurred or has been primarily responsible for metal damage. For instance, fretting may have initially produced alpha Fe_2O_3 and then long exposure to moisture occurred to hydrate it to $Fe_2O_3.H_2O$—this occurrence would be just the reverse of the "heating of rust" possibility cited above. Case histories from the field, therefore, are very important in arriving at an accurate diagnosis.

MECHANISM OF FRETTING CORROSION

There are two main schools of thought as to how fretting corrosion occurs. These two hypotheses fall into the "chicken

Fig. 1 Galled arbor from bearing test machine. Cantilever loading of test bearing on section just to left of shoulder, as viewed above, results in flexing of galled tapered portion of arbor in tapered housing, with result as shown

and the egg" category. To state the problem as succinctly as possible—which comes first, the oxidation of the metal surface followed by abrading off of Fe_2O_3 or the abrading off of virgin iron particles which subsequently and rapidly oxidize to Fe_2O_3?

Fink[4], Dies[5], and also Sakmann and Rightmire[6] have postulated the chemical oxidation theory. Their experiments indicate that less fretting corrosion is obtained in a vacuum or in the presence of an inert gas. They believe, therefore, that this phenomenon is correctly called "friction oxidation," and that local high temperatures are necessary to produce the primary oxidation of the surface.

On the other hand, various investigators, including Tomlinson et al[7, 8] of England and Godfrey[9] of the National Advisory Committee for Aeronautics believe that oxidation is secondary and that fretting corrosion is due primarily to "molecular plucking"; that is, when two ferrous surfaces are very clean the molecules of one pull out the molecules of the other by molecular attraction. These very fine particles then immediately oxidize (if oxygen is present) to give the usual alpha Fe_2O_3 fretting corrosion debris.

The idea of chemical attack in the case of fretting corrosion is not borne out by the behavior of stainless steel. This material is very susceptible to fretting corrosion, but, as is well known, not to chemical corrosion. Also fully oxidized materials, such as ruby and glass, will show fretting.

Even though the experiments of Fink[4] and others indicate that surfaces are less damaged when rubbed together in a vacuum, this may be due to less abrasion from Fe_2O_3 because there is less of that oxide formed (in the absence of oxygen) to abrade the surfaces. It has been definitely shown that surface damage increases sharply as debris such as Fe_2O_3 accumulates. This material, hematite, is known as "jeweler's rouge" and is used as a lapping agent in the polishing of jewelry.

Godfrey's recent article[9], published in February, 1950, presents classically simple experiments to settle the old question concerning the mechanism of fretting corrosion. Essentially, Godfrey's equipment was a microscope with a suitable solenoid actuating mechanism which vibrated a convex surface in contact with a stationary flat surface. Frequencies of 60 cycles or less than 1 cycle per second, an amplitude of 0.001 inch, and a load of 0.2 pound were used.

Godfrey's observations and analyses lead to the conclusions that fretting is caused by the removal of "finely divided and apparently virgin material due to inherent adhesive forces, and that its primary action is independent of vibratory motion or high sliding speeds." Materials other than metal-to-metal combinations were tried, including fully oxidized compounds such as quartz and mica, and the noble metal platinum. Finding that these materials also showed fretting "corrosion," appears to relegate the role of oxidation to a secondary factor.

A typical experiment of Godfrey was that of vibrating a chrome-alloyed steel ball against a glass specimen plate and observing what happened under the microscope. In this case (with clean surfaces) fretting becomes evident as a small black spot on the ball within one-fourth second. A brown sticky semi-fluid oxide is then generated within the contact area, and finally a rust-colored fine, dry oxide is also formed that accumulates just outside the rubbing area. As the lower oxides of iron (FeO and Fe_3O_4) are black whereas ferric oxide (Fe_2O_3) is red, the above color changes indicate a progressive oxidation of the abraded-off iron.

As mentioned previously, the fact that platinum produces a fine black powder of the virgin metal, which of course does not oxidize under atmospheric conditions, and also the fact that fully oxidized quartz, ruby, et cetera, may be fretted readily, strengthens the hypothesis that the primary action is one in which the very clean surfaces produced by rubbing allow the surface molecules to come within their attractive range, and therefore "molecular plucking" of surface particles occurs.

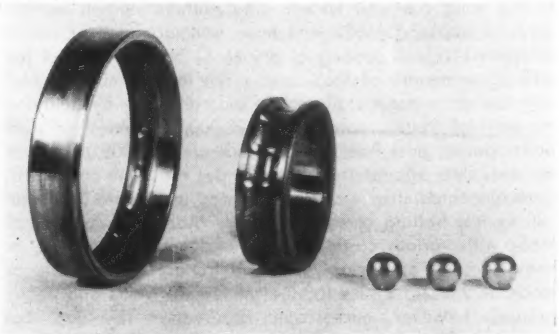

Fig. 2 Failure of bearing as a result of vibration with bearing not rotating—a severe example of fretting corrosion

EFFECT OF CONDITIONS ON FRETTING CORROSION

EFFECT OF LOAD: Fretting corrosion is obtained both under high and low loads though the type of bearing is a factor concerning the damage which occurs. High load accelerates fretting of anti-friction bearings as greater areas of contact are obtained through Hertz deformation and more slip is obtained. This condition does not hold true for plain bearings. In the latter case, lessening the load produces no signficant decrease of fretting corrosion. Sometimes the best fix in the case of plain bearings is to suppress vibration by means of a heavy clamping load.

EFFECT OF LUBRICANT: The presence of an oily or greasy substance between two surfaces slows up but does not overcome fretting corrosion. In the case grease application, relubrication is of definite assistance because the

purging effect flushes out the Fe_2O_3 debris and thus alleviates lapping of the surfaces. Even an oil does not prevent fretting, as once wear starts and a dam of debris is built up, fretting becomes self-accelerating[10].

Both past and present findings indicate that very soft consistency grease lubricants and, of course, completely fluid oils, are most effective in minimizing fretting corrosion[11]. Obviously, submerging the surfaces protects against oxidation and promotes the positive feeding of lubricant which keeps the molecular attractive forces of the bearing surfaces from coming within range of one another. Of course, the problem here is retaining a fluid or semi-fluid lubricant. In some cases, this is very difficult sealing problem and a compromise must be made toward using a more viscous lubricant.

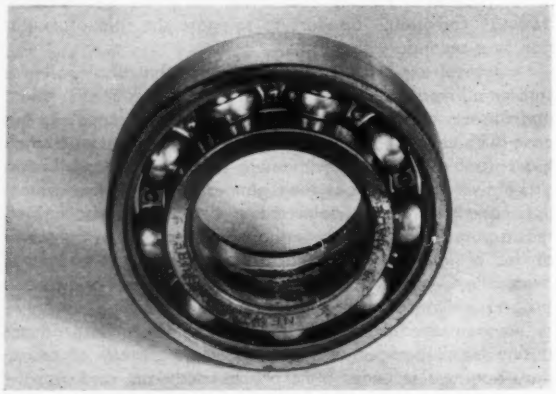

Fig. 3 Example of fretting corrosion on inner ring of ball bearing as a result of loose fit between ring and shaft

Recently, results have been reported by Godfrey and Bisson[10] on the effectiveness of molybdenum disulfide as a fretting-corrosion inhibitor. The friction-reducing properties of this solid are well known. The authors studied various ways of applying MoS_2, and have summarized their results as follows: "1. A coating of dry MoS_2 bonded to steel (by rubbing a mixture of MoS_2 and syrup into intimate contact with the clean hot metal) proved most effective by delaying the start of fretting corrosion to 28,000,000 cycles for steel balls against glass flats and approximately 10,000,000 cycles for steel flats against steel flats. Under the same conditions, clean uncoated steel specimens showed immediate (less than 100 cycles) fretting corrosion. 2. Dry MoS_2 and mixtures of MoS_2 with various carriers (water and aerosol, light oil, or heavy grease) appreciably delayed fretting corrosion (to as much as 216,000 cycles for the mixture of MoS_2 and heavy grease); however, microscopic observation revealed that MoS_2 may have been ineffective at the contact area. In the mixtures, it is possible that the carrier alone was responsible for the beneficial action. 3. Observations indicated that the effectiveness of any fretting-corrosion inhibitor is dependent on its ability to prevent metallic adhesion continuously."

EFFECT OF FITS: Close fits are desirable. In the assembly of anti-friction bearings, such as needle bearings in helicopter rotor flap hinges, it has been mentioned by Rahm and Wurster[12] that refined internal tolerances were a factor in correcting fretting corrosion. Looseness of fits promotes relative motion other than normal antifriction bearing action.

EFFECT OF SURFACE FINISH AND MATERIALS: There are some data to show that smoother surfaces allow worse fretting; this is understandable as there is more chance for molecular attraction in such cases because the surfaces are closer together. Rahm et al[12] of Wright Field have presented data to show that vapor blasting (satinizing) cuts down fretting damage.

Surfaces of like composition are more susceptible to fretting corrosion and to wear than are surfaces of unlike finish or composition.

EFFECT OF TEMPERATURE: Further work by Godfrey[8] indicates that "hot spots" or high temperatures are not a prerequisite of fretting corrosion, as he obtained glass-steel fretting under a very slow transverse motion (0.002 in. per second) where it was very improbable that high spot temperatures existed. This finding is further confirmation of the theory that fretting corrosion is due to short-range molecular attractive forces rather than by effects induced by frictional high temperatures.

COOPERATIVE WORK ON FRETTING CORROSION

WORK OF THE COORDINATING RESEARCH COUNCIL, INC.: The CRC has been asked by the Military, primarily the U.S. Air Force, to cooperate on solving the problem of how to evaluate lubricants regarding their efficacy in mitigating fretting corrosion. This work comes under the Airframe Lubricants Group of the CRC. The main Group has been divided into a Service Evaluation Division and a Laboratory Study Division.

Fretting corrosion is being studied under both of the above divisions. The Laboratory Panel has the assignment of developing a research technique to allow the determination of the anti-fretting-corrosion properties of greases. Cooperative samples of lubricants which are being currently evaluated by the Laboratory Panel have also been made available to the Service Evaluation Panel so that aircraft field tests may be run concurrently with the laboratory tests.

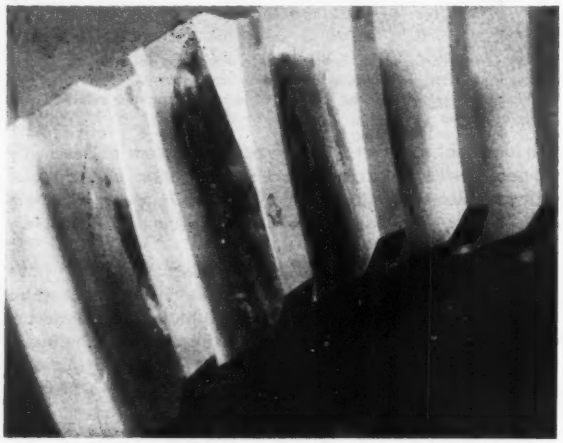

Fig. 4 Severe fretting corrosion on aircraft gears as a result of high frequency vibration under high load.

Phase One of the work of the Laboratory Panel is the study of the Fafnir Bearing Company type Friction-Oxidation Tester[13]. This apparatus has recently been modified, and information on the new design may be obtained by communicating with the Fafnir Bearing Company, New Britain, Connecticut. The tester utilizes two thrust ball bearings as test speciments. Weight loss after running under predetermined conditions is taken as the criterion of performance.

The following conditions are now being studied by the Laboratory Panel:

Load, lbs.	550*
Oscillation°	12 and 3
Frequency RPM	1725
Time, hours	50 (5,175,000 cycles)
Temperature	Room
Grease charged, grams	1 ± 0.05 per bearing
Type of bearing	Fafnir No. 4305S thrust bearing

* 2000 lbs. being investigated by certain laboratories.

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Lubrication Summarized

WEAR OF METALS AND THE MECHANISM OF LUBRICATION

by A. R. Black, Shell Oil Co., ASLE Buffalo Section Meeting.

Wear may be divided into the following categories: 1. Cutting—of soft metal by rough surface of hard metal, 2. Abrasion—involving a third grit-like solid component, 3. Galling or scuffing—tearing away of metal from one surface and pick-up on mating surface resulting from high-spot welding, 4. Corrosion—induced by products of combustion in internal combustion engines, 5. Pitting—considered largely a metallurgical and surface finish problem, with possible promotion by hydraulic action of lubricant in fatigue cracks, 6. Fretting Corrosion—"molecular plucking" of small particles of metal from surfaces subjected to imperceptive relative motion or vibration.

The approach to wear prevention by lubrication presupposes a knowledge of the region of lubrication prevailing.

In the hydrodynamic region, proper lubricant viscosity at the temperature of the fluid film is the important factor. The viscosity should be high enough to maintain a sufficiently thick film but not high enough to cause excessive friction and consequent temperature rise.

In the boundary region, viscosity is secondary to "oiliness"—obtained by additives of polar compounds, mild EP agents or chemical polishing agents.

Under extreme pressure conditions, provision for surface contamination to prevent seizure and welding is necessary. Since these EP agents are required to react chemically with the surface, the net result is an increase in wear during the run-in period, but a general over-all improvement of surfaces which otherwise would have been destroyed during the initial run-in.

The distinction between EP agents and "oiliness" agents is that the latter are effective below the seizure point, conditioning surfaces at low temperatures, while the EP agents are active only at the high temperatures due to metal-to-metal contact.

Still another type additive, used to offset corrosive wear, must be active at low operating temperatures, since corrosive wear in internal combustion engines has been found to vary inversely with temperature.

The life of mechanical equipment can be lengthened considerably by cooperation of the designer, the metallurgist and the lubrication engineer to reduce working surface wear.

RE: OPERATION OF INTERNAL COMBUSTION ENGINES

by J. J. Fahey, P.M.S., Inc., ASLE Baltimore Section Meeting.

The successful operation of an internal combustion engine depends largely upon the ability of the motor oil to furnish continuous lubrication to all bearing surfaces. It is generally conceded that stable oils do not wear out in performing their specific duty of overcoming friction between bearing surfaces. Nevertheless, it is common observation that motor oils undergo chemical and physical changes while in operation. These changes result as expressed from the operation of the engine, its design and maintenance, and the fuel used, through admixtures of dilution, water and solids, the degree varying with the individual engine.

In the continental U. S. the operating conditions for motor vehicles are subject to wide variations. Not only are the seasonal fluctuations in temperatures to be encountered, but also differences in operating temperatures resulting from changes in geographical and climatic conditions; also operating routes and the type of service in which the vehicle is employed. Obviously, it is not practical to design each vehicle to fit each particular set of circumstances under which it may be used. If practical to do so, maintenance, lubrication and operating costs would be correspondingly controlled. Consequently, as operating conditions diverge from the normal toward any extreme, performance is likely to become less satisfactory unless these changes are met by effective preventive maintenance procedures and modifications.

The operator, especially in commercial operation, who is confronted with the necessity for maintaining the minimum cost per mile, has the responsibility for curtailment of tangible expenditures. In this connection is the establishment of "Optimum Oil drain periods." They realize the need for circumventing possible troubles, due to deterioration and contamination, by draining the crankcase periodically. Actually there is no basis for standard agreement regarding the mileage or time for which oil can be used before draining, nor are there any reliable simple test methods for predetermining the useful life of an oil from its specifications.

Engine wear from abrasion by dust, dirt and solid particles finding entrance with intake air to the induction and ventilating systems is considerably more prevalent than is generally realized. Considerable research has been accomplished in evaluating the effects of air cleaners and the necessity for the best possible maintenance of same. With an efficient air cleaner average cylinder wear was reduced 76%, ring wear reduced between 68 to 88%, and valve stems 56%.

Of paramount importance are the by-products of "incomplete combustion," which consists principally of fuel dilution, combustion soots, lead compounds of treated gasolines and moisture. Engines in "average" type service are subject to low cylinder wall temperatures, condensation, etc. and resultant washing of these combustion by-products past the pistons and into the oil. If crankcase temperatures are undesirably low and if the engine suffers from poor ventilation, moisture and volatile fuel contaminants are not removed from the oil. These contaminants in the oil then accumulate and increase in quantity until a critical point is reached wherein they begin to coagulate and separate out as "sludge deposits." In this initial state of formation, the sludge can then settle out as deposits. Inasmuch as these contaminations can be identified through chemical analysis and correlated as to their origin for corrective actions at their inception confirms the necessity for periodic oil sample analysis as an aid in establishing the basic lubrication difficulties from which progressive reduction of faulty conditions can be realized.

In summary, each operator's set of operating conditions which proportionally affects lubrication efficiency must be established and treated accordingly. The analysis system employed must be sufficiently flexible so as to evaluate accurately what these requirements are rather than any empirical standard system for treatment of all recommendations alike.

METALWORKING & FORMING COMPOUNDS

by E. L. H. Bastian, Shell Oil Co., ASLE St. Louis Section Meeting.

Dual-purpose and multi-purpose oils (inactive type with little compounding) are satisfactory for some machining work in addition to the recommended lubrication and hydraulic applications, dependent upon severity of machining requirements.

Magnesium is always machined with inactive oil type fluids, tools kept sharp, reasonably heavy cuts taken, and chips removed frequently from machines to avoid dangers from fire. Water base fluids are never used since, in event of a chip fire from frictional ignition, the intense heat of combustion would re-

(Continued on page 208)

Lubrication in the News

RECOMMENDED PRACTICES FOR THE CLEANING OF TURBINE LUBRICATING SYSTEMS is the title of a new 15-page booklet prepared by the Joint ASTM-ASME Committee on Turbine Lubrication and published by The American Society of Mechanical Engineers. It contains the proposed recommended practices for: (1) the preparation of new turbine lubricating systems, (2) the cleaning of turbine lubricating systems after service, and (3) the purification of turbine oils. Available at $1 per copy from ASME Order Dept., 29 W. 39th St., New York 18, N. Y.

AEROLUBE 51 is a new lubricating oil additive formulated for use in premium grade motor oils to inhibit oxidation of motor oils, protect bearings from corrosion, and provide engine cleanliness. Generally employed at concentrations in the range of 0.5% to 1.0% by volume, depending upon the base stock to be treated and the performance requirements of the finished oil, in addition to its oxidation and corrosion inhibiting properties it provides adequate protection against the foaming tendencies of motor oils. For further information write American Cyanamid Co., 30 Rockefeller Plaza, New York 20, N. Y.

DESCO MOBILE LUBRICATION SERVICE, a new type of valve lubrication service for the petroleum and chemical industry, has been introduced to take over the responsibility of positive and proper lubrication and adjustment of all valves on the customer's property and is accomplished with a fleet of trucks especially designed and equipped to serve chemical plants, refineries, tank batteries, gathering lines or the entire length of a pipeline. Each truck is a complete and independent unit, manned by a trained crew of lubrication specialists, and equipped with every possible tool and fitting for servicing any valve including WKM, Nordstrom, Walworth, and all other makes of lubricated valves. High pressure equipment is capable of delivering 180 pounds of lubricant per hour. For further information write Desco Service Co., 804 Louisiana Ave., Shreveport, La.

NORGREN ¾" & 1" AIR LINE FILTERS WITH REPLACEABLE TRANSPARENT BOWL, a new filter for removal of corrosive moisture, abrasive pipe scale and other foreign matter from ¾" and 1" compressed air lines, are now available for use on air flows from 0 to 140 cfm at pressures of 0 to 150 psi and temperatures between 40 and 120F. The transparent plastic bowl, which holds one pint below the baffle, is easily removed for cleaning or replacement—the filter is fully automatic, requires no adjustments, and its special baffle plate traps the moisture and solids in the bottom of the bowl where they cannot be drawn back into the air line. Complete information available by writing C. A. Norgren Co., 3400 S. Elati, Englewood, Colo.

HOUGHTON DIE CASTING LUBRICANTS, expressly devoloped to provide clean, accurate castings, longer die life and more economical production, are heat resistant, form a tough, protective film over dies and tools, and are easily cleaned from castings which are to be plated or otherwise finished. For complete descriptive bulletin, write E. F. Houghton & Co., 303 W. Lehigh Ave., Philadelphia 33, Pa.

LAMINIC: FUEL & WATER TANKS, newly-developed of American Cyanamid's LAMINAC polyester resin reinforced with Owens-Corning's FIBERGLAS mat, are being used by The Arabian American Oil Co. on its trucks that carry fuel and water across Saudi Arabian deserts. Expected to last from 10 to 50 times as long as steel tanks, the plastic tanks cannot rust, do not corrode from the salt in crude and refined petroleum, because of their lighter weight they can be made larger than those of steel, adding substantially to the payload, both the water and fuel-carrying tanks have smooth inside surfaces that can be steamed clean, and in the case of a ruptured area are quickly closed and reinforced with plastic-impregnated FIBERGLAS mat included in a repair kit. For further information write American Cyanamid Co., 30 Rockefeller Plaza, New York 20, N. Y.

TOKHEIM INDUSTRIAL HAND PUMP, newly designed to handle a wide variety of liquids used in industry, makes use of specially-developed internal parts designed to withstand the action of a variety of other liquids. Capable of pumping many types of acetates, alcohols, glycols, ketones, ethers and plasticizers, it has also been found suitable for aromatic, chlorinated and petroleum solvents. For further information write Tokheim Oil Tank & Pump Co., Fort Wayne, Ind.

LET'S LOOK IT UP is the title of the complete new 1952 catalog of technical books describing in detail the books of the Reinhold Publishing Corp., including all the American Chemical Society Monographs. The following are some of the new books described: Physical Chemistry of Lubricating Oils, Light Hydrocarbon Analysis, Engineering Materials Manual, Surface Chemistry of Solids, Physical Chemistry of Surface Films, Chemical Engineering Techniques, and Performance of Lubricating Oils. Copies available from H. Brunell, Reinhold Publishing Corp., 330 W. 42nd St., New York 36, N. Y.

AQUADAG USED IN DENTAL DIE ELECTROFORMING: In the process of making dental dies by electroforming, original wax or other compound impressions must be coated with an electrical conductor in order to be able to accept the metal deposit and thin enough so as not to affect the dimensions of the die formed from the impression. Aquadag, a dispersion of colloidal graphite in water possessing dry lubricating as well as electrically conductive properties, permits the die to separate smoothly and easily from the impression. For information write Acheson Colloids Co., Port Huron, Mich.

LINCOLN AIR-MOTOR OPERATED PUMPS AND ACCESSORIES for automatic application of heavy to light materials, such as sealers, adhesives, roofing, waterproofing, insulating, and caulking compounds have been catalagued by the manufacturer. Catalog No. 40 available upon request from Lincoln Engineering Co., 5743 Natural Bridge Ave., St. Louis 20, Mo.

NEW STANDARD: B16.20-1952 RING JOINT GASKETS & GROVES FOR STEEL PIPE FLANGES. An authoritative source of information for the size designation of rings, each of the existing 92 rings having its own designation, and, if a need for new rings should arise, can be assigned additional numbers to be recorded in the next revision of the standard. Copies available at $1 from the American Standards Association, 70 E. 45th St., New York 17, New York.

MOLYKOTE-CENTERLUBE, a new lubricant for dead center lubrication wherever loads and speeds are beyond the capacity and temperature ranges of conventional center lubricants, whose basic ingredient is a lubricating grade of molybdenum disulfide powder which will bond a lubricating film on bearing surfaces and impart the low friction and anti-seizing properties necessary to resist extreme bearing pressures and temperatures, has proven highly successful for steady rest lubrication and for reducing wear on plug and thread gages. For complete details write The Alpha Corp., 179 Hamilton Ave., Greenwich, Conn.

Current Literature

ASTM BULLETIN, No. 181, April, 1952, Measurement of Extreme Pressure Properties of Lubricants (Report of Special Committee of ASTM Committee D-2 on Petroleum Products and Lubricants), by H. Levin, H. G. Sprague, and Collaborators. The paper describes the committee's activities toward standardizing and improving the reproducibility of the Timken test as used to measure extreme pressure properties of lubricants. An appendix describes the improved Timken procedure and is published as information only. The test may be used to place a lubricant in one of three extreme pressure levels, namely, low, medium, or high.

CHEMICAL ENGINEERING, Vol. 59, No. 4, April, 1952, New Fluorocarbon Products, Anon. Mention is made of a new line of oils, greases, and waxes developed by M. W. Kellog Co. In the series of Kel-F products, these materials are chemically inert fluorocarbons and will withstand high temperature, high electrical resistance, and corrosion. Applications are suggested. No other details are given.

CHEMICAL WEEK, Vol. 70, No. 23, June 7, 1952, Fortified For Service, Anon. Brief review of history and use of lubricating oil additives is given. About 30 million gallons will be used this year: by 1955, 50 million gallons may be used.

CHEMIE INGENIER TECHNIK, Vol. 24, No. 1, January, 1952, Molecular Flow Through Composite Pipe Lines, W. Harries. The author gives formulae for the flow resistance, which differ in some details from the conventional, commonly accepted expressions.

CHEMISTRY & INDUSTRY, No. 14, April 5, 1952, A Simple Semi-Micro Viscometer For Thick Liquids, N. A. de Bruyne. Diagrams illustrate the construction of the simple, easily cleaned, absolute viscometer, made primarily of glass. Sample required is small so that temperature equilibrium is readily attained. Viscosity of an oil using this instrument was 3.96 poises, as compared with 3.91 poises as determined independently on other equipment.

DIESEL POWER, Vol. 30, No. 3, March, 1952, Some Factors in Accessory Equipment Selection as Applied to Filders—Oil and Lube, Anon. The main purpose of lube oil filtration is protection of bearings and oil passages. The approach most commonly used is to collect all foreign matter appearing in the lube oil, down to a known particle size. It is common and practical to use, in connection with filter-strainers, some type of bleeder or bypass type filter. The filter-strainer does not collect soft carbons or asphaltines which result from heat and pressure exerted on the oil. A fundamental reason for use of a bypass filter is to keep oil passages from clogging. Filter selection and operation are considered.

FETTE UND SEIFEN, ANSTRICHMITTEL, Vol. 54, No. 3, March, 1952, Analysis of Lead Naphthenates, A. Castiglioni. The author describes method of determining lead content of commercial lead naphthenate.

INDUSTRIAL AND ENGINEERING CHEMISTRY, Vol 44, No. 5, May, 1952, Corrosion, M. G. Fontana. Several methods used in the literature for presenting or summarizing corrosion data are discussed. The writer points to the "Corrosion Data Survey" by the Shell Development Co. as the best and most complete compilation of corrosion data.

INDUSTRIAL LABORATORIES, Vol. 3, No. 5, May, 1952, Permanent Lubricating, Anon. "Lead-Lube"—a heavy duty grease lubricant with an extremely high metallic lead content in the form of pulverized dust, kept in suspension by a new homogenizing process—is believed by company which developed it (Knapp Mills, Inc., Long Island City, N. Y.) to be the nearest approach to a permanent lubricant thus far achieved.

INSTITUTE SPOKESMAN, Vol. 15, No. 12, March, 1952, The Four-Ball E. P. Tester, D. K. Nason. The Shell Four-Ball Extreme Pressure Tester, described in this article, is used to investigate changes in the Navy procedure in order to shorten the time required to determine the Mean Hertz Load value of a lubricant without sacrificing the accuracy of the original Navy test. This is a simplification of the Mean Hertz Load Test Procedure and is used in the industry as a test for screening the extreme pressure properties of grease as well as gear oils. This test procedure has now superseded the earlier Pressure Wear Index Method in Government specification. A complete description of the tester and its use is given.

Vol. 16, No. 1, April, 1952, Atlantic Refining Announces "Robot Brain" to Probe Secrets of Oil, Anon. The Atlantic Refining Co. announced recently the development of "robot brain" which will analyze petroleum products in one-tenth the time required by existing methods. This modern analytical tool will analyze a mere trace of gas or liquid, and in a matter of minutes record the complete chemical composition on a typed sheet of paper. This was achieved by the linking together of an electronic counter and a mass spectrometer. The "robot brain" was described by Dr. W. S. Young of Atlantic's Philadelphia research staff, at the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy held in the William Penn Hotel.

Vol. 16, No. 2, May, 1952, Maintenance Lubrication of Ball and Roller Bearings, R. L. Wheeler. This is an outstanding article containing considerable detail. The paper is confined primarily to the lubrication of the conventional types of ball and roller bearings in the field. It is not intended to cover the lubrication of pre-packed or so-called lifetime lubricated bearings. A short discussion is included on cleaning anti-friction bearings, followed by a brief outline as to the cause and prevention of bearing failure. The following subjects are taken up: lubrication—related to machine design, functional requirements of lubricant, frictional losses, bearing seals, heat dissipation, corrosion prevention, selection of lubricating oils, selection of lubricating greases, multi-purpose lubricants, lithium base greases, barium base greases, strontium base greases, bentone greases, special greases, grease consistency, quantity and frequency of application, cleaning anti-friction bearings, and bearing failures—causes and prevention.

LUBRICATION, Vol. 38, No. 5, May, 1952, Non-Ferrous Metals. Lubrication of Mining, Concentrating and Smelting Machinery, Anon. Mining operations can be divided roughly into two types, i.e., open pit or surface mining, and underground or shaft mining. Modern mining has become largely electrified, consequently air power and electric power predominate below ground. While the type and extent of refinement of the lubricants employed have much to do with efficient operation of any rock drill or pneumatic tool, the means whereby the former are admitted or distributed have a marked effect upon their ability to function effectively. Rock drill lubricants are refined to function with a minimum of fluid friction, and a maximum of sealing power in the prevention of air blowby past the pistons. Air line oilers are generally intended for the handling of fluid oils. The pulsation type lubricator operates through the action of the reciprocating piston. Rock drill lubricants are specialty products, prepared to meet certain specific conditions of operation and means of application in drills, stopers, and drifters. Lubrication of various types of equipment is considered.

OILDOM, Vol. 30, No. 14, April 21, 1952, Navy Lubricant System Ends Jamming of Guns, Anon. A lubricant system developed by chemists of the Naval Research Laboratory of the Office of Naval Research allows Navy and Marine Corps aviators to fire their 20-millimeter M3 automatic aircraft cannon at altitudes of 30,000 feet and higher. The guns frequently jammed because petroleum lubricants then being used solidified in temperatures of 20 degrees below zero and lower. Four synthetic lubricants make up the new system: (1) a light oil for the gun mechanism itself; (2) a lubricant for the ammunition; (3) a water-repellant lubricant for the electric trigger, and (4) a grease for the mechanism that automatically feeds the ammunition to the gun.

PETROLEUM ENGINEER, Vol. 24, No. 5, May, 1952, Facilities For Research, J. I. Mattill. Petroleum and fuels engineering is a fast-growing field in colleges and universities. Already these teaching programs have generated substantial resources for fundamental research to serve the industry. In 1951, 65 colleges and universities told the Engineering College Research Council that nearly 200 faculty members qualified to do research in the petroleum and fuels field were available on their staffs. Of these, few more than 100 had research underway. The full report of the survey, entitled "University Research Potential," identifies all schools reporting personnel, competencies, and equipment. Copies are available from the Secretary of the Engineering College Research Council at Room 7-204, 77 Massachusetts Ave., Cambridge 39, Mass., at $1 each.

New Lubricant Announced After 5 Years Experiment, Anon. A permanent suspension of finely divided lead metal in greases, lead which is actually in dust form, has produced a lubricant that is a homobeneous blend and that offers decided advantages, according to Knapp Mills, Inc. The lead coats surfaces of rubbing parts with a protective layer that protects the surface underneath both from frictional damage and from corrosive action, lead being impervious to many corrosive chemical agents.

PLANT ENGINEERING, Vol. 6, No. 5, May, 1952, Oil Reclaim Systems I—What Are the Various Types and Their Advantages?, J. O. O'Connell. Advantages and disadvantages of the following types of oil reclaim systems in general usage are described briefly: filtered type filter, single plate replaceable filter, multi-plate replaceable filter, permanent filter, automatic self-cleaning filter, sedimentation, and centrifugal separation.

SCIENTIFIC LUBRICATION, Vol. 4, No. 5, May, 1952, Oil Flow in Plain Journal Bearings, Anon. A simplified method of analysis for the rate of oil flow in plain journal bearings has been developed by S. A. McKee, head of the National Bureau of Standards (U.S.A.) engines and lubrication laboratory. This problem is important to bearing design and operation; an adequate oil flow is essential to insure not only the maintenance of a load-carrying oil film, but also the disposal of frictional heat developed in the bearing. The new method indicates that flow of oil from the ends of plain journal bearings fed through an oil hole, an

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Section News

BALTIMORE

April 1952 meeting—Re: Operation of Internal Combustion Engines, by J. J. Flahey, P.M.S., Inc. (See Lubrication Summarized). (Submitted by H. A. Rau, Jr., Sec'y-Treasurer.)

BOSTON

March 1952 meeting—Dr. W. H. Millett, Carbide & Carbon Chemicals Corp., presented an address entitled Synthetic Lubricants.

May 1952 meeting—Mr. G. H. Link, Shell Oil Co., presented an address entitled Anti-Friction Bearing Greases.

Boston Section Officers and Committee Chairmen for the ASLE 8th Annual Meeting, Boston, April, 1953, have been announced as follows: Chairman—A. S. McNeilly, Esso Standard Oil Co.; Vice-Chairman—E. M. Wiggins, Master Lubricants Co.; F. M. Dohl (Connecticut Section Representative), U. S. Hoffman Corp.; R. E. Scully (Rhode Island Section Representative), Grinnell Corp.; Treasurer—H. E. Wilson, Commercial Filters Corp.; Program Committee—O. S. Edmiston, Atlantic Refining Co.; Arrangements Committee—E. B. Harvey, Jr., Fiske Bros. Refining Co.; Entertainment Committee—J. L. Morosini, D. A. Stuart Oil Co.; Newspaper Committee—J. R. Clarke, Jr., Esso Standard Oil Co.; Publicity Committee—H. G. Senning, E. F. Houghton Co. (Submitted by A. S. McNeilly, Sec'y).

BUFFALO

May 1952 meeting—Mr. J. Coghill, Vice-President of the Curlator Corp., and designer of the Curlator machine; a unique process for paper pulp, discussed some of the unusual design and lubrication problems encountered in developing this machine, using large drawings and photographs for illustration.

June 1952 meeting—Wear of Metals and the Mechanism of Lubrication, by A. R. Black, Shell Oil Co. (See Lubrication Summarized). Submitted by W. H. Miller, News Committee Chairman.)

CONNECTICUT

May, 1952 meeting—Following the annual election of officers (See Directory), a film on Rust Control was shown followed by a panel discussion on Rust Prevention with A. W. Ackerman, F. E. Anderson Oil Co., as speaker, and panelists C. T. Hewitt, Fafnir Bearing Co., E. Worden, Stanley Works, C. Gillette, New Departure Div., and H. Fishbeck, Pratt & Whitney Aircraft. (Submitted by J. S. Martin, Sec'y Treasurer.)

DAYTON

March 1952 meeting—Mr. B. E. Nagel, General Motors Research Laboratories, discussed Automotive Greases, calling attention to various types of greases, their characteristics, applications and limitations, to the inadequacy of many grease specifications, and to the need for more thorough test methods.

April 1952 meeting — Mr. H. E. Mahncke, Westinghouse Research Laboratories, presented an address entitled Dry Friction and Lubrication, discussing the various components of friction obtained when one surface is moved across another and explaining the behavior of dry lubricants, particularly graphite and molydisulfide.

May 1952 meeting—Mr. G. Sumner, Westinghouse Electric & Mfg. Corp., spoke on Electric Motor Lubrication, stressing the importance of proper design for lubrication, the various types of lubricants used for electric motor lubrication and their limitations. (Submitted by V. C. Hutton, Sec'y.)

KANSAS CITY

June 1952 meeting—Executive Committee Meeting, covering plans for future section meetings and increasing membership, with the following appointments announced: Membership Chairman—W. P. Johnston, Sinclair Refining Co.; Publicity Chairman — A. Steenhof, Mid States Lubricants Co., and Program Chairman—L. M. Feiff, Bowser, Inc. (Submitted by C. C. Schrotberger, Sec'y-Treasurer.)

KINGSPORT

March 1952 meeting—Mr. T. R. Witt, Tennessee Eastman Co., presented a paper dealing with the lubrication program and achievements in the Textile Divisions of Tennessee Eastman, followed by the annual election of officers (See Directory).

June 1952 meeting—Mr. M. R. Tyson, Vickers Incorp., presented a paper entitled Why Oil Hydraulics?, illustrated with films and slides. Excerpts from his paper include: "Oil Hydraulics, by terminology of recent years has been used more and more often to define that branch of hydraulics developed specifically for the purpose of operating industrial machines as apart from the field of hydraulics dealing with civil engineering problems such as flood control, hydro-electric dams, navigation locks and other jobs of the same general nature. The Science of Oil Hydraulics can be explained as being an extremely flexible and accurate means of transmitting energy from a source to a point or points on a machine for the purpose of performing useful work. Generally speaking, pumps are designed to receive rotary mechanical energy and from this, generate hydraulic energy in the form of a stream of fluid. Rotary hydraulic motors receive energy from a stream of fluid and transform this energy into rotating mechanical energy. In any hydraulic system, FORCE is the result of pressure, DIRECTION is the result of direction of flow, and SPEED is the result of volume of flow. Controlling these three, i.e., FORCE, DIRECTION, and SPEED, in a manner to cause the machine to operate correctly is the essence of any machine hydraulic circuit.

There is no fluid except oil that can meet all requirements of modern day machine hydraulic systems. If the question is posed, "Why Oil Hydraulics?" meaning why are oil hydraulics used on representative machines in almost every type industry today, the answer cannot be categorical, but must cover the special requirements of each of the machines as well as the characteristics of the oil hydraulic systems used on them." (Submitted by J. E. Fleenor, Sec'y-Treasurer.)

LOS ANGELES

April 1952 meeting—Dr. U. B. Bray, Bray Oil Co., presented a discussion entitled Rust Preventives, in their broad aspect, covering types, manufacture, composition and application. (Submitted by R. C. Dishington, Sec'y-Treasurer.)

MILWAUKEE

May 1952 meeting—Annual Installation of Officers (See Directory) and Party. (Submitted by R. W. Schroeder, Sec'y.)

NEW YORK

May 1952 meeting—Following the annual election of officers (See Directory), Mr. H. Muller, retiring Chairman, outlined the accomplishments of the section during the previous year, and Mr. A. M. Morrow, Shell Oil Co., spoke on Cleaning Lubricating Systems, covering the importance of system cleaning in various types of machinery and the various methods employed to do the job. (Submitted by E. Landau, Sec'y.)

NORTHERN CALIFORNIA

May 1952 meeting—Mr. N. W. Bjerre, Office of Naval Material—San Francisco, presented a discussion entitled The Inspection Service With Regard to Petroleum and Related Prod-

(Continued on page 209)

Patent Abstracts

Prepared by ANN BURCHICK from Official Gazette—Vol. 657, No. 5; Vol. 658, Nos. 1, 2, 3, 4; Vol. 659, Nos. 1, 2, 3. Printed copies of patents are available from the Patent Office at twenty-five cents each. Address the Commissioner of Patents, Washington, D. C., for copies and for general information concerning patents.

MINERAL OIL COMPOSITIONS, Patent #2,594-279, L. E. Beare, assignor to Sinclair Refining Co. A lubricating oil composition comprising predominantly a mineral oil and containing minor but effective proportions for extreme pressure properties of an oil-soluble stable chlorinated hydrocarbon containing about 35 to 75% chlorine and a composition of matter prepared by the reaction of a bicyclic terpene, sulfur, and a phosphorus sulfide in the approximate molar ration 3-8:0.5-5:1, the said composition of matter containing sulfur within the range from 10.56 to 16.17% by weight and containing phosphorus within the range from 1.65 to 3.46% by weight.

GREASE AND GREASE BASE, Patent #2,594,286, W. C. Bryant and H. Frost, Jr., assignors to Swan-Finch Oil Corp. A grease composition comprising a petroleum lubricant and a sufficient quantity of a gelatin agent to cause at least a partial gelatin thereof.

LUBRICATING COMPOSITION, Patent #2,594,-795, L. L. Neff, assignor to Union Oil Co. of Calif. A mineral lubricating oil containing a small proportion, between about .02% and about 15% by weight, of a compound selected from the class of compounds of the oil-soluble condensation products of a hydrocarbon substituted phenol with acetylene and oil-soluble metal salts of said condensation products, said condensation product being obtained by reacting said phenol with acetylene at a temperature between atmospheric temperature and about 300 C. and at a pressure between about 5 and about 30 atmospheres for a time sufficient to absorb between about .05 and 2 mols of acetylene per mol of phenol.

PREPARATION OF GREASES, Patent #2,594,822, F. H. Stross and R. J. Moore, assignors to Shell Development Co. In a process for the formation of a grease, the steps comprising dispersing an alcoholate of a polyvalent metal in a lubricating oil, hydrolyzing said alcoholate to form a polyvalent metal hydroxide and removing non-metallic hydrolysis products.

OXIDATION RESISTANT LUBRICATING OIL COMPOSITION, Patent #2,595,140, R. L. Heinrich, assignor, by mesne assignments, to Standard Oil Development Co. An Oxidation resistant lubricating oil composition which comprises a polymer boiling in the lubricating oil boiling range of an alpha olefin having from 5 to 10 carbon atoms in the molecule, said polymer having lubricating oil properties and being susceptible to oxidation and not less than 0.1% by weight of carbazole.

LUBRICATING COMPOSITION, Patent #2,595,-161, A. J. Morway and D. W. Young, assignors to Standard Oil Development Co. A lubricating grease composition consisting essentially of a lubricating oil thickened to a grease consistency with a metal soap of a fatty acid having combined therein a minor but oxidation resistance improving amount of bis (5-methyl-2-hydroxy phenyl) sulfide.

STEAM TURBINE LUBRICANTS, Patent #2,595,-169, H. W. Rudel and J. I. Wasson, assignors to Standard Oil Development Co. A lubricating composition consisting essentially of mineral base lubricating oil containing 0.01 to 0.5% by weight, of a compound selected from the class which consists of thioether substituted tetrahydrophthalic and hexahydrophthalic acids, and the anhydrides, and monoesters thereof having at least one thioether substitution including one organic radical attached in alpha position to an acyl radical through a thioether linkage.

LUBRICATING OIL ADDITIVES, Patent #2,595,-819, W. H. Smyers and D. W. Young, assignors to Standard Oil Development Co. A lubricating oil composition comprising a major proportion of a mineral lubricating oil base stock, containing dissolved therein about 1 to 20% by weight of a P_2S_5 reaction product of a solution of about 20% by weight of a styrene-isobutylene copolymer having a combined styrene content of about 50% and an intrinsic viscosity of about 0.5 to 1.5, in about 80% by weight of sperm oil, said reaction product containing between 1 and 10% sulfur and 0.1 to 5% phosphorus by weight.

FILTRATION OF OILS AND WAXES WITH BAUXITE, Patent #2,596,942, D. W. Robertson and C. F. Duchacek, assignors to Socony-Vacuum Oil Co., Inc. That method of reducing the color of petroleum stocks such as oils and waxes by filtration with bauxite in a state of hydration obtained by heating the bauxite to a temperature of the order of 750 F. for a period of two hours and then adding thereto at least about 2% by weight of water, based upon the heated bauxite weight.

LUBRICANT, Patent #2,597,018, R. L. Merker and C. R. Singleterry. A thickened lubricating composition comprising a lubricating oil and up to about 45% by weight of a phthalocyanine dispersed therein in a proportion sufficient to cause gel formation in the oil.

STABILIZED HYDROCARBON LIQUIDS, Patent #2,597,205, T. B. Tom, assignor to Standard Oil Co. A composition consisting essentially of a hydrocarbon oil distillate, containing a sulfur compound corrosive to copper as a constituent thereof, and from about 0.005% to about 1%, by weight, of the oil-soluble fraction of olibanum.

STABILIZED PHOSPHORUS AND SULFUR-CONTAINING HYDROCARBON REACTION PRODUCTS AND COMPOSITIONS CONTAINING THE SAME, Patent #2,597,750, E. N. Roberts and L. W. Mixon, assignors to Standard Oil Co. A lubricant composition containing a major proportion of an oil and from about 0.001% to about 10% of a metal salt of the product obtained by reacting from about 1% to about 50% of a phosphorus sulfide with a normally liquid hydrocarbon at a temperature of from about 200 F. to about 600 F., neutralizing said reaction product with a basically reacting metallic compound and reacting the neutralized product with from about 0.5% to about 40% of a quinone at a temperature within the range of from about 100 F. to about 400 F.

LUBRICANT CONTAINING SELENIUM COMPOUNDS, Patent #2,597,838, W. Lowe, W. T. Stewart, and J. O. Clayton, assignors to California Research Corp. A lubricant consisting essentially of a major portion of a selenium-containing lubricating oil composition corrosive to silver, and a small amount, sufficient to inhibit the formation of silver selenide resulting from the selenium attack on silver, of a 2-mercapto-thiozine wherein not more than four of the ring carbons contain aliphatic groups each of which has not more than 4 carbon atoms.

PRODUCTION OF LUBRICATING OIL, Patent #2,597,908, H. R. Stewart and W. M. Thaw, assignors to California Research Corp. A process for producing lubricating oil from petroleum wax which comprises the steps of chlorinating the wax to such a degree that the whole reaction product of the chlorination step has a chlorine content in excess of 20% by weight and catalytically dehydrochlorinating said reaction product by contacting it with at least 5% by weight of a silica-alumina catalyst at a temperature in the range about 600 to 725 F. for a time sufficient to substantially completely remove the chlorine from the chlorinated wax and to produce a relatively saturated oil.

PROCESS FOR MAKING GREASE, Patent #2,-598,154, G. C. Bailey and W. B. Whitney, assignors to Phillips Petroleum Co. A process for manufacturing a grease from an oil and a metallic soap which comprises the steps of forming a mixture comprising a metallic soap with a hydrocarbon lubricating oil, heating said mixture with agitation to substantially disperse the soap in the oil, chilling suddenly to form a hard friable gel in some free oil, separating said gel from a portion of said free oil, and working said gel and remaining free oil to a state of substantially constant consistency.

LUBRICATING OIL ADDITIVES, Patent #2,599,-337, E. Lieber and E. P. Cashman, assignors to Standard Oil Development Co. 1. A Process which comprises reacting a chlorwax-naphthalene condensation product having a molecular weight of at least 1,000 and having pour depressing properties with benzine sulfonyl chlorine in the ratio of about 1 to 50 parts by weight of sulfonyl chloride per 100 parts by weight of chlorowax-naphthalene condensation product in the presence of a Friedel-Crafts catalyst hydrolyzing and removing residual catalyst and subjecting the reaction product to distillation under reduced pressure up to a temperature of about 600 F. to obtain the desired final condensation product as distillation residue. 6. Composition comprising a major proportion of a lubricating oil base-stock and 0.05% to 10% by weight based on the lubricating oil base-stock of a product comprising essentially a benzene sulfonyl halide derivative of a long chain aliphatic-aromatic Friedel-Crafts condensation product having a molecular weight of at least 1,000, said composition having an improved pour point and improved pour stability.

HIGH TEMPERATURE LUBRICATING GREASE MANUFACTURE, Patent #2,599,343, A. J. Morway and J. J. Kolfenbach, assignors to Standard Oil Development Co. The process of preparing a lubricating grease which comprises mixing about 1 to 5 parts by weight of a saponifiable fatty acid having between about 12 and 22 carbon atoms with about 3 to 10 parts of a mineral base lubricating oil, adding a strong metal base in excess to saponify said fatty acid, adding about one-fourth to 2 parts of an aldehyde of molecular weight less than C_{12} fatty acids and capable of undergoing the Cannizzaro reaction in the presence of said base to form the corresponding salt in the presence of said lubricating oil and saponified fatty acid, heating to above 210 F. but not above about 340 F. with mixing to remove water and to substantially evaporate alcohol released in said Cannizzaro reaction, and further cooking and blending in additional lubricating oil to form a grease of the desired consistency.

STAINLESS EMULSIBLE GREASE, Patent #2,599,-353, J. C. Showalter, assignor, by mesne assignments, to Standard Oil Development Co. A stainless, emulsible grease composition which comprises 25% to 75% by weight of a base oil containing alkali metal petroleum sulfonates in an amount in the range between 10% and 15% by weight of said base oil, the remainder being

(Continued on page 210)

Book Reviews

PETROLEUM DICTIONARY AND PRODUCTS MANUAL
by Petroleum Educational Institute, Publishers, Dept. E, 9020 Melrose Ave., Los Angeles 46, Calif., 1952, 502 pages, 6164 entries, 2113 illustrations, price $8.00.

PETROLEUM DICTIONARY AND PRODUCTS MANUAL, a valuable aid to buyers, sellers, consumers, and salesmen of petroleum products, particularly those who do not possess a technical background, is not only a dictionary but also gives information on the fundamentals and application of petroleum products as well. Given are simple, understandable definitions of the many technical and semi-technical terms generally found in periodicals, books, and other literature in connection with the application and use of petroleum products and what these tests mean to sellers, buyers, and users of petroleum products. Included are definitions of hundreds of lubricating and other oils, more than a score of different gasolines, information about the additives generally used in present day fuels and lubricants, terms connected with the origin, history, drilling, and production of crude oil, and descriptions of diesel and spark engines. By so doing the book becomes more than a dictionary—it becomes virtually a practical education in the vital subject of products information, a manual on the most common petroleum products used in the automotive, agricultural, textile, mining, lumbering, steel, railroading, ceramic, refrigeration, paper, food and many other industries.

TECHNIQUES OF PLANT MAINTENANCE—1952
by Clapp and Poliak, Inc., Publishers, 341 Madison Ave., New York 17, N. Y., 1952, 182 pages, price $6.00.

TECHNIQUES OF PLANT MAINTENANCE—1952, a comprehensive discussion of plant maintenance problems compiled from the proceedings of the annual Plant Maintenance Conference & Show, is highlighted by the text of 717 questions propounded by 2,100 engineers from every major industry in the country who attended the sessions and represents the best cross-section of current industrial engineering thought on maintenance problems. Texts at panels by 36 outstanding leaders in the field are illustrated by 49 charts, diagrams, graphs, and tables, and are divided into groups of general and specific interests followed with an elaborate question-and-answer section. General topics include costs, inspection methods and records, planning and scheduling maintenance work, and lubrication. There are chapters on maintenance of electrical equipment, plant buildings, training maintenance workers and supervisors, and project preparation and cost control. Separate treatment of maintenance problems, according to the size of the plant, is given in five chapters, beginning with plants employing less than 50 maintenance workers, and ending with plants having more than 800. Chemical, steel, and automotive plants have separate chapters.

Coming Events

AUGUST

11-13—Socy. of Automotive Engineers (national West Coast meeting), Fairmont Hotel, San Francisco, Calif.

19-22—American Inst. of Electrical Engineers (Pacific general meeting), Westward Ho Hotel, Phoenix, Arizona.

SEPTEMBER

4-5—National Conference on Industrial Hydraulics, Hotel Sherman, Chicago, Ill.

8-9—National Symposium on the Fundamentals of Friction and Lubrication in Engineering, Hotel Sherman, Chicago, Illinois.

8-11—Socy. of Automotive Engineers (national tractor meeting and production forum), Hotel Schroeder, Milwaukee, Wisc.

9-11—Oil Industry Information Committee, The Traymore Hotel, Atlantic City, N. J.

9-13—National Chemical Exposition — 7th (Trail Blazers' section), Coliseum, Chicago, Ill.

10—American Petroleum Institute (Division of Marketing, Lubrication Committee), The Traymore Hotel, Atlantic City, N. J.

10-12—National Petroleum Assn. (50th annual meeting), The Traymore Hotel, Atlantic City, N. J.

11-13—American Inst. of Chemical Engineers, Palmer House Hotel, Chicago, Illinois.

14-19—American Chemical Society (122nd national meeting, Petroleum Division), The Traymore Hotel, Atlantic City, N. J.

17-18—National Industrial Conference Board, Waldorf-Astoria Hotel, New York, N. Y.

22-24—American Trade Assn. Executives (annual meeting), Royal York Hotel, Toronto, Ontario.

23-24—American Petroleum Institute (Executive Committee of the Board of Directors), Greenbrier Hotel, White Sulphur Springs, W. Va.

25-26—Mid-Continent Oil & Gas Assn. (Louisiana-Arkansas Div. annual meeting), The Roosevelt Hotel, New Orleans, La.

25-27—Independent Oil Compounders Assn. (5th annual meeting), Edgewater Beach Hotel, Chicago, Illinois.

OCTOBER

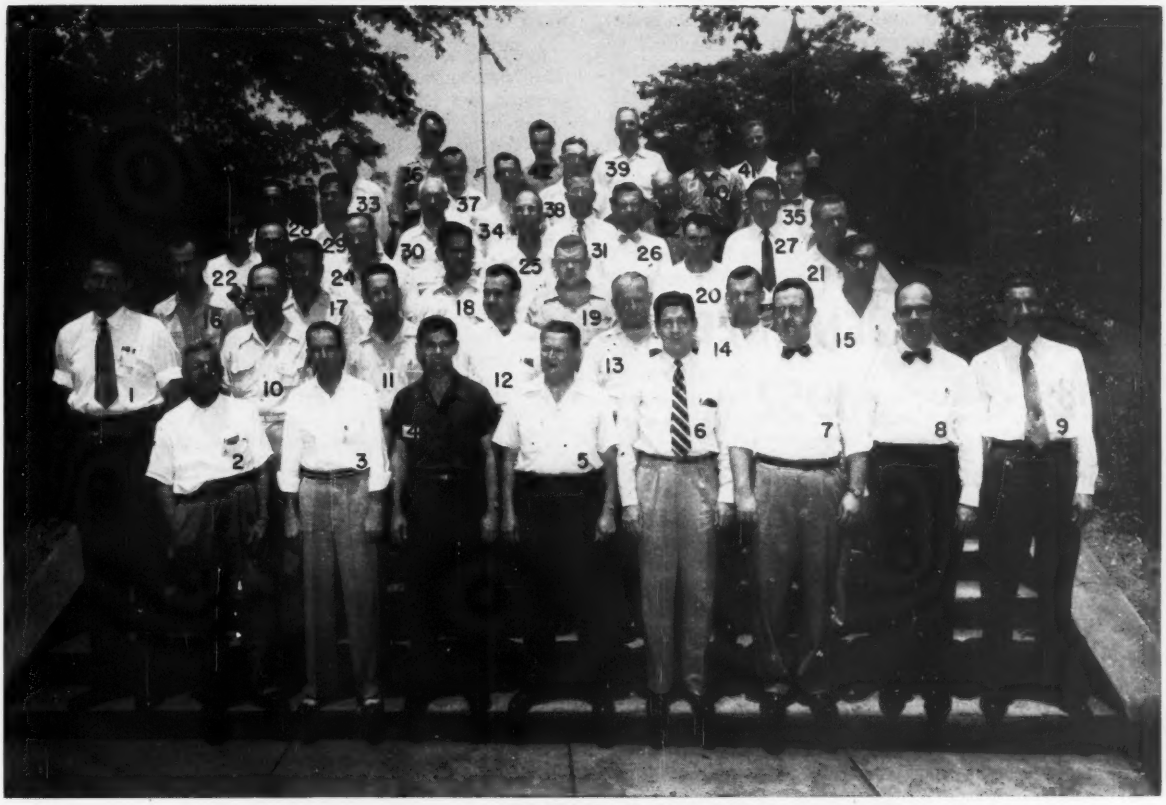
1-3—American Inst. of Mining and Metallurgical Engineers (petroleum branch—Mid-Continent fall meeting), The Rice Hotel, Houston, Texas.

1-4—Socy. of Automotive Engineers (national aeronautic meeting, aircraft engineering display, and production forum), Hotel Statler, Los Angeles, Calif.

9-10—California Natural Gasoline Assn. (27th annual fall meeting), The Ambassador Hotel, Los Angeles, Calif.

Personals

Sinclair Research Laboratories, Inc., announces the promotions of W. M. FLOWERS to President, with offices in N.Y.C., E. J. MARTIN, instrumental in planning Sinclair lubrication refining facilities and in the development of new lubricants, to the post of Vice-President and General Manager, and C. J. FRANCISCO, author of several patents involving the processes for the production of better and more economical petroleum products, to the post of Manager in Charge of Technical Activities, both for Sinclair's Harvey Research Center . . . R. J. HAGAN, Republic Steel Corp., charter member and director of the ASLE Youngstown Section, died May 14, 1952 . . . A. E. CICHELLI has been promoted to Chief Lubrication Engineer of the Bethlehem Steel Corp., Sparrows Point, Mo. . . . THE SPARKLER MFG. CO., manufacturers of filtration equipment for industrial, commercial, institutional, and domestic use, has opened a branch office and warehouse to serve the West coast, 612 N. San Vicente Blvd., Los Angeles 46, Calif., and has appointed R. E. SHIELDS as West Coast Sales Manager . . . L. H. NORGREN has been appointed Plant Superintendent of the C. A. Norgren Co., pneumatic products manufacturer, Englewood, Colo. . . . New officers for the American Society for Testing Materials include: President—H. L. MAXWELL, E. I. du Pont de Nemours & Co., Inc.; Vice-President—N. L. MOCHEL, Westinghouse Electric Corp.; Board of Directors — G. R. GOHN, Bell Telephone Laboratories, W. H. LUTZ, Pratt & Lambert, Inc.; H. K. NASON, Monsanto Chemical Co.; A. O. SCHAFFER, The Midvale Co., and M. A. SWAYZE, Lone Star Cement Corp. . . . F. D. TUEMMLER, Shell Development Co., received an ASTM 1952 Award of Merit for significant and valued service in the work of Committee D-2 on Petroleum Products and Lubricants.—(NOTE: Submit copy for any LE feature to Editorial Assistant, LUBRICATION ENGINEERING, 343 S. Dearborn St., Chicago 4, Ill.)



LUBRICATION ENGINEERING COURSE

GEORGIA INSTITUTE OF TECHNOLOGY

June 16-27, 1952

Forty students from U.S.A., Canada, British West Indies, and Netherlands West Indies attended the ASLE sponsored Lubrication Engineering Course at Georgia Institute of Technology in Atlanta, June 16-27, 1952. The program was arranged by Prof. D. D. Fuller of Columbia University, ASLE Director and Chairman of the ASLE Education Committee, and directed by Dr. J. P. Vidosic of the School of Engineering, Georgia Institute of Technology. Lecturers for the course were: Dr. M. E. Merchant, Cincinnati Milling Machine Co., ASLE President; Prof. D. D. Fuller; J. Boyd, Westinghouse Electric Corp., ASLE Director and Chairman ASLE Bearings and Bearing Lubrication Technical Committee; D. Cleaveland, Bendix Aviation Corp., Chairman ASLE Lubricant Reclamation & Disposal Technical Committee; O. Frohman, Ampco Metals Co., Chairman ASLE National Symposium Program Committee; Dr. J. P. Vidosic; Dr. E. M. Kipp, Aluminum Co. of America; A. Cichelli, Bethlehem Steel Corp.; T. R. Witt, Tennessee Eastman Co.; C. M. Weckstein, Timken Roller Bearing Co.; J. L. Brusca, SKF Industries, Inc.; S. D. Craine, W. A. Jones Foundry & Machine Co., and C. Hubbard, Deering Milliken Co.

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3 D. B. Powers
4 F. C. Ludden
5 J. F. Collins
6 H. G. Lane
7 E. M. Kipp
8 W. P. Youngclaus, Jr.
9 J. P. Vidosic
10 F. C. Eaton, Jr.
11 L. G. Compton, Jr.
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16 C. M. Doering
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18 J. P. Ellis
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20 V. V. Motley, Jr.
21 E. P. Viar
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27 J. M. Mathers
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35 L. E. Locke, Jr.
36 R. C. Gebhardt
37 R. E. Forsythe
38 J. R. Lawrence
39 L. W. Simmons
40 R. W. Petersen
41 R. S. Nowell
42 R. G. Forsythe
* L. R. Dubuque
* M. M. Springer

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* Not in photograph

Plan to attend the

CENTENNIAL OF ENGINEERING

1852 1952

in conjunction with

THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS'

First National Symposium

on

Fundamentals of Friction and Lubrication in Engineering

(Victor A. Ryan Memorial Symposium)

SEPTEMBER 8 and 9, 1952, HOTEL SHERMAN, CHICAGO

PROGRAM

Sept. 8,	10:00 A.M.	HISTORICAL DEVELOPMENT OF MODERN LUBRICATION CONCEPTS
	2:00 P.M.	FUNDAMENTALS OF HYDRODYNAMIC LUBRICATION
Sept. 9,	9:30 A.M.	PHYSICS AND CHEMISTRY OF RUBBING SOLIDS—TECHNICAL APPLICATIONS
	1:30 P.M.	PHYSICS AND CHEMISTRY OF RUBBING SOLIDS—BASIC PRINCIPLES

(Lube Lines, Continued from 173)

remain in equilibrium for that speed and load condition, varying only with the temperature of the surrounding air. The lubricant, when cold, may be of exactly the proper viscosity to keep the surfaces apart. However, the heat generated within the oil itself through fluid friction may be sufficient to lower the viscosity so that actual striking of the high points of the surfaces will take place. It is necessary, therefore, to use a heavier oil than that theoretically required, depending upon the heat of operation to bring it to the desired viscosity for the machine condition. The frictional resistance of the machine will be high when starting, but the operation will be safe and free from wear at running temperatures. When the heat generated in a bearing equals the heat radiated, the body of the oil remains steady and the power required for the operation is likewise steady.

NATIONAL CONFERENCE ON INDUSTRIAL HYDRAULICS

The eighth annual National Conference on Industrial Hydraulics, sponsored by Illinois Institute of Technology in conjunction with the Centennial of Engineering, will be held September 4 and 5, 1952, at the Hotel Sherman, Chicago, Ill. The schedule and agenda for the sessions is as follows: Thursday, September 4, 10 A.M., Low Temperature Application of Industrial Hydraulic Oils by D. K. Nason, The Texas Co., Beacon Laboratories; Hydraulic Equipment, Design, Construction and Maintenance by J. R. Hemeon, General Motors Corp.; 2:00 P.M. Hydraulic Steering in General Motors Cars by C. W. Lincoln, General Motors Corp.; Commercial Vehicle and Passenger Car Power Braking by W. R. Williams, Bendix Aviation Corp.; Instrument Maintenance in an Oil Refinery by W. A. Theissen, Standard Oil Co. of Indiana; Air Operation of Hydraulic Gauges and Controllers in Water Filter Plants by A. A. Kalinski; Design Features of a High Pressure Single Stage Rotary Vane Hydraulic Pump Motor by J. R. English, The Denison Engineering Co.; Noise in Hydraulic Pumps by E. L. Midgette, Polytechnic Institute of Brooklyn; Friday, September 5, 9:30 A.M., Techniques in Machine Tool Circuit Design by E. Y. Seborg Barnes Drill Co.; Air-Powered Hydraulics by P. E. Butzin and C. Johnson, Rockwell Mfg. Co.; Jet Engine Fuel Pumps by J. A. Lauk, Borg-Warner Corp.; Design for Increased Reliability of Aircraft Hydraulic Systems by L. M. Chattler, Navy Dept.; Anti-Racing Hydro-Brake for Adjustable Blade Propellers and Propeller Turbines by P. W. Seewer, The English Electric Co., Ltd.; Hydraulically Operated Intake Gates—McNary Dam Powerhouse by R. G. Neighorn, North Pacific Div., Corps of Engineers; 2:00 P.M., Control of Large Direct Hydraulic Presses by F. H. Towler, Towler Brothers Ltd.; Double Action Hydraulic Press Circuits by P. J. Lindner, Hydraulic Press Mfg. Co.; 17 Ton Payload Concrete Hauling Unit Having Hydraulically Powered Tractive Effort and Hydraulic Mixing by J. F. Oury, Imperial Construction Equipment Co.; Hydraulics of Tractor Loaders for Mining by J. J. Slomer and M. G. Carlson, Goodman Mfg. Co.; The Surface Type Seal—For Tougher Jobs by R. O. Isenbarger, Chicago Rawhide Mfg. Co; Tube and Tube Fittings by L. Schmohl, The Parker Appliance Co.; Portable Tube-Working Tools by G. Franck, Imperial Brass Mfg. Co.

PHYSICAL PROPERTIES OF LUBRICANTS

INTRODUCTION: Wherever two resistant bodies are in contact and move relative to one another, friction results. It matters not if they be huge building blocks for the pyramids of Egypt dragged by straining slaves, or a giant Mount Palomar telescope floating effortlessly in its bearings as it follows the night stars. Throughout the centuries from bullock-

(Continued on page 206)

(Christensen, Continued from page 179)

Results of the bulk oil oxidation and corrosion tests conducted on inhibited fluids for 168 hours at 250F., for 20 hours at 347F., and for a time approximating the stable life of the lubricant at 347F. are shown in Table VI. Also shown, for comparison purposes is the oxidation and corrosion stability of an ester-base fluid without E.P. additives and of a Specification MIL-0-6086, Grade M, fluid (a medium grade, petroleum-base gear oil containing a sulfur-chlorine type additive). This latter oil is used by the military services. Figure 2, a graph of neutralization number versus test time, depicts the stable life test data at 347F. of some fluids shown in Table VI. The tests indicate that the stable life of the petroleum oil is less than 168 hours at 250F. and less than 20 hours at 347F. under the previously described test conditions. The di-2-ethylhexyl sebacate with phenothiazine is stable for well over 168 hours at 250F. The stable life of the sebacate-phenothiazine blend at 347F. is approximately 100 hours. The effects of the E.P. additives in the ester during the oxidation and corrosion tests, were a higher total acid number at all points of oxidation time, a fairly steady increase in neutralization number with time and relatively high copper corrosion. Many of the 347F. tests also showed high magnesium corrosion. The presence or absence of 1.0 weight percent of an organophosphate had little effect on the results of the oxidation and corrosion tests.

The use of sulfurized hydrocarbon E.P. additives produced excessive copper corrosion but showed little evidence of corrosion of other metals even under the high temperature conditions. Mercaptobenzothiazole was added to fluid blends containing sulfurized hydrocarbons in an attempt to control copper corrosion. In all cases the mercaptobenzothiazole increased the neutralization number of the blend, and at the same time reduced the copper corrosion. While definitely lowered, the copper corrosion was still as high or

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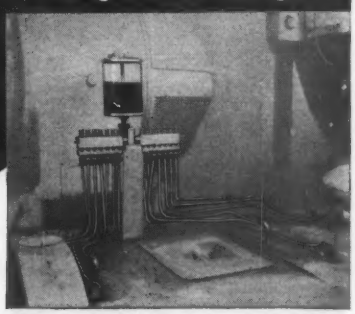

THREE MULTI-POINT automatic oilers saved $206 in one year for a large manufacturer by replacing 30 manually operated cups formerly used on the machine. Easily adjustable oil flow to all points cut machine's oil need 50%, and eliminated over and under lubrication, spillage, burned-out bearings. Oiler maintenance was cut from 30 fillings per day to 3 every third day. Solenoids connected across line of drive motor control oilers, eliminating 60 start-stop operations. Oilers can be filled while mill is running.

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higher than that noted with sulfur-chlorine additives. Copper corrosion values for the experimental blends incorporating thiophosphates were among the lowest of any class of E.P. additives tested. No corrosion was noted with the other four catalyst metals.

Results of several experimental lubricants in the thin-film oxidation tests are shown in Table VII. A Specification MIL-O-6086 Grade M petroleum oil has been included for comparison. The petroleum oil showed high fluid deterioration under the thin-film test conditions. The ester-base blend containing a sulfur-chlorine additive and an organophosphate formed somewhat less sludge. Tests with a blend containing a sulfurized hydrocarbon and one blend with Triphenylthio phosphate show relatively high silver corrosion. These results are in good agreement with the bulk oil oxidation and corrosion test results for 20 hours at 347F. It has been found that the relative tendency to cause silver corrosion and the tendency to cause copper corrosion is about the same.

The thin film oxidation test reproduces the same sort of deposits on the steel jack chain and the sliver-plated steel as were noted in the bearings of a turbo-prop engine. It is believed these engine deposits could not be quantitatively anticipated on the basis of oxidation and corrosion tests other than the thin-film type test.

IV. WEAR AND LUBRICATION PROPERTIES OF EXPERIMENTAL FLUIDS AFTER OXIDATION TESTS

The acceptable lubricant for use in the turbo-prop engine and gear box must retain its lubrication qualities under high-temperature oxidation and corrosion conditions. Therefore, an important phase in the development program was the determination of lubricating qualities of various blends after the laboratory oxidation and corrosion tests.

TABLE V
WEAR CHARACTERISTICS OF EXPERIMENTAL GEAR BOX LUBRICANTS
Test Apparatus: Shell four-Ball Extreme Pressure Tester, SKF Industries Grade No. 1 (0.5 in diameter) Steel Ballbearings

TEST FLUID COMPOSITION NUMBER	APPROX. LOAD FOR INCIPIENT SEIZURE, KG.	AVERAGE WEAR SCAR DIAMETER, MM STEEL-ON-STEEL BEARING SURFACES							
		40 Kg.	60 Kg.	80 Kg.	120 Kg.	160 Kg.	200 Kg.	240 Kg.	280 Kg.
A	70	0.34	0.39	0.56	1.62	2.16	2.47	3.12	Welded
B	40	0.42	2.08	2.60	Welded				
C	50	0.47	2.03	4.55	Welded				
D	50	0.31	1.88	2.51	2.77	Welded			
E	75	0.36	0.47	0.68	1.90	2.29	Welded		
F	100	0.33	0.42	0.42	0.78	2.03	2.53	Welded	
G	70	0.36	0.56	0.68	1.90	2.38	Welded		
H	75	0.33	0.40	0.58	1.10	2.21	2.15	2.14	2.47
I	90	0.34	0.36	0.56	1.30	1.45	1.95	2.10	2.40
J	65	0.36	0.51	1.86	1.95	2.16	3.25	Welded	
K	60	0.38		1.43	1.69	1.90	2.34	2.64	Welded
L	80	0.30		0.39	1.88	2.25	2.73	Welded	
M	80	0.33	0.36	0.42	2.21	2.68	Welded		
N	80	0.33	0.35	0.42	1.82	2.34	Welded		
O	80	0.33		0.42	0.78	2.34	Welded		
P	60	0.33	0.39	2.40	Welded				
Q	70	.032	0.35	2.29	2.98	Welded			

The wear characteristics of many of the oxidized blends containing extreme pressure additives were studied under critical loads in the Shell Four-Ball Extreme Pressure Tester.

The wear data show a significant decrease in both the estimated point of incipient seizure, and the point of permanent welding for the Specification MIL-O-6086, Grade M, petroleum base gear lubricant. Composition F shows the best general wear properties after oxidation of all blends tested containing sulfur-chlorine type additive.

The point of permanent welding for the sulfurized hydrocarbon-containing blends after oxidation tests were somewhat lower although still higher in comparison to those for any of the other E.P. additives tested.

Based on anti-wear, extreme pressure lubrication, oxidation and corrosion stability, and other properties, composition F was chosen for testing in a turbo-prop engine and gear box unit. The composition and some characteristic properties of this blend appear in Tables III, IV, V and VI. Some additional properties are listed as follows:

Viscosity, cs. at 210F.	5.59
Viscosity, cs. at —40F.	3,4000
Pour Point, °F.	<—75
Flash Point, °F.	450

Conclusions, based on data obtained from the testing of composition F in a turbo-prop unit, were that the lubricant performed excellently on gears but had poor high temperature characteristics in the power section components. Modification of the E.P. additive was considered necessary since excessive corrosion and sludge formation result from the contact of copper and silver with the additive. It was decided that attempts would be made to develop anti-wear

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V. MODIFICATION OF COMPOSITION F

An alternative was to eliminate all conventional E.P. additives since they display undesirable corrosive action toward copper and silver. One possibility was the use of organophosphorus type anti-wear additives. It was already known that their use improved the anti-wear properties of fluids on the basis of the Shell Four-Ball wear tests. The investigation of the phosphate type additives was extended to include a total of nine phosphate materials. Various percentages of these materials in esters were evaluated for anti-wear and extreme pressure properties. The compositions and some physical properties of the more promising phosphate type additives appear in Tables III, IV, V, VI, and VII.

The wear values of organophosphate—containing fluids are much lower than those of the base fluid. The point of incipient seizure for the fluid with 5.0 weight percent of a phosphate is approximately 70 kilograms. This value is the same as for the MIL-O-6086 extreme pressure gear oil. However, the mineral oil has a greater load carrying capacity following immediate seizure on the E.P. tester than does

TABLE VI
OXIDATION CHARACTERISTICS OF EXPERIMENTAL GEAR BOX LUBRICANTS

FLUID COMPOSITION NO.		A			B[2]			F			G
TEST TIME, HOURS	168	20	38	168	20	103	168	20	80	168	80
TEST TEMPERATURE, °F.	250	347	347	250	347	347	250	347	347	250	347
% Increase in Viscosity											
at 130F.	+16	+37	+38	4	4	19	4	3	9	2	2
at 0F.	+250	+514	+1130	7	2	42	5	−2	1	4	11
Neutralization No.											
Original	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Final	1.8	2.3	5.3	0.5	1.1	11.0	0.8	1.8	4.1	0.7	2.5
Final Catalyst Condition											
Copper	C[1]	C	C	D	D	D	C	C	C	C	C
Steel	B	D	D	D	Co	D	D	D	Co	D	D
Aluminum	B	B	B	D	D	D	D	D	D	D	D
Magnesium	D	D	D	D	D	D	D	C	Co	D	C
Cd-plated Steel	D	D	D	D	C	C	Co	Co	Co	Co	C
Wt. Loss (mg./sq.cm.)											
Copper	15.8	9.68	10.01	0.04	0.00	0.02	3.97	12.70	13.45	20.60	16.27
Steel	0.00	0.06	0.09	+0.01	+0.05	+0.05	+0.02	0.24	+0.09	+0.02	0.05
Aluminum	0.01	0.02	0.02	+0.05	+0.02	+0.06	+0.02	+0.04	+0.06	+0.07	+0.07
Magnesium	0.01	0.01	0.01	+0.04	+0.05	+0.03	+0.03	1.77	+0.09	+0.01	5.03
Cd-plated Steel	0.01	0.11	0.18	0.00	4.50	1.64	+0.35	+0.62	+0.93	+0.02	0.22
Cd-plated Steel		H[2]			I[2]		M		N	P	Q
FLUID COMPOSITION NO.	168	20	59	168	20	60	20	168	20	20	20
TEST TIME, HOURS	250	347	347	250	347	347	347	250	347	347	347
TEST TEMPERATURE, °F.											
% Increase in Viscosity	4	4	8	0	3	6	4	3	5	3	4
at 130F.	6	4	8	0	5	7	2	4	6	6	5
at 0F.											
Neutralization No.	0.3	0.3	0.1	1.3	1.7	1.4	4.8	0.1	0.1	0.1	0.1
Original	2.7	3.8	6.3	4.3	2.3	5.2	2.3	0.4	1.1	1.1	1.3
Final											
Final Catalyst Condition	C	C	C	C	C	C	C	C	C	D	D
Copper	D	D	D	B	D	Co	D	B	B	D	D
Steel	B	D	B	B	D	Co	B	B	B	D	D
Aluminum	B	D	B	B	D	Co	B	B	B	D	B
Magnesium	D	D	D	B	D	Co	D	B	B	C	C
Cd-plated Steel											
Wt. Loss (mg./sq.cm.)	66.3	136	155	11.2	24.2	26.8	3.43	14.1	9.43	0.02	0.00
Copper	0.0	0.02	0.0	0.0	0.05	+0.09	+0.01	0.00	0.00	0.00	+0.05
Steel	+0.02	+0.02	0.0	0.00	+0.06	+0.07	0.00	0.00	0.01	0.00	+0.04
Aluminum	0.00	+0.02	0.00	0.00	+0.03	+0.06	+0.02	0.00	+0.01	0.00	+0.05
Magnesium	0.00	+0.02	0.01	0.00	+0.04	+0.06	+0.02	0.01	0.02	0.65	1.55

[1]Code: B—Bright, D—Dull, Co—Coated, C—Corroded
[2]With phenothiazine

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the ester fluid containing 5.0 weight percent of an organophosphate.

On February 14, 1951, a conference was held at the Wright Air Development Center, Dayton, Ohio, to discuss the formulation of the new turbo-prop fluid. The conference was attended by members of industry, the Air Force, the Navy Bureau of Aeronautics, and the Petroleum Refining Laboratory. Conclusions reached were (1) that the new lubricant formula should essentially match composition F in all respects except the E.P. additive, (2) from the results of previous wear studies only an organophosphate would be incorporated as an anti-wear and extreme pressure additive, and (3) the concentration of this additive would be either 3.0 or 5.0 weight percent depending on further studies to be conducted at the Petroleum Refining Laboratory on wear and oxidation stability.

Five weight percent of organophosphates showed better wear characteristics compared to 3.0 weight percent in a typical ester-base fluid. Thus the first step was to retain the blend with the 5.0 weight percent concentration and test the lubricant further for signs of a decrease in stability or increase in corrosiveness.

In the thin-film test the stability of lubricants containing 1.0, 3.0 and 5.0 weight percent of these antiwear additives did not vary significantly from the phenothiazine-inhibited base stock. No appreciable silver corrosion was noted with blends containing 3.0 or 5.0 weight percent organophosphates. In the case of Composition F, oxidative deterioration is quite severe under the thin-film test. Based on these results, the phosphate additives appeared to be promising as anti-wear and E.P. agents suitable for use in turbo-prop gear lubricants.

The use of phosphate additives in 3.0 or 5.0 weight percent concentrations did not significantly alter the bulk oil oxidation or corrosion stability of phenothiazine inhibited di-2-ethylhexyl sebacate.

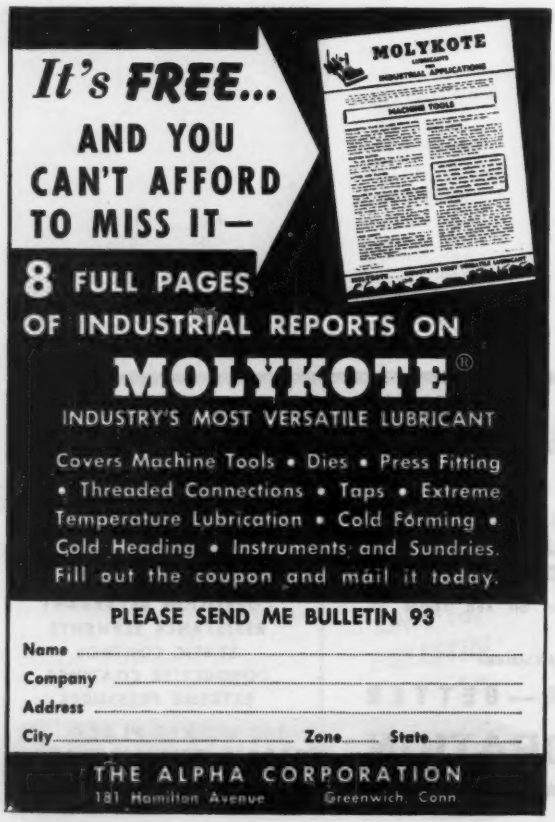
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TABLE VII

OXIDATION CHARACTERISTICS OF EXPERIMENTAL GEAR BOX LUBRICANTS (THIN FILM CONDITIONS)

TEST FLUID COMPOSITION NO.	A	B[1]	I[1]	N	P	Q
% Increase in Viscosity						
at 130F.	32	4	6	2	4	5
at 0F.	26	8	9	3	7	7
Neutralization No.						
Original	0.1	0.1	1.3	0.1	0.1	0.1
Final	12.6	1.1	2.0	1.5	1.0	0.9
Final Catalyst Condition						
Steel	Coated	Dull	Coated	Dull	Dull	Dull
Ag—Plated Steel	Dull		C'ro'd'	C'ro'd'	Dull	Dull
Pb—Indium-Plated Steel					Bright	Dull
Wt. Loss (Mg./sq.cm.)						
Steel	+0.19	+0.02	+0.09	+0.04	+0.04	+0.03
Ag—Plated Steel	+0.41		27.15	4.84	0.00	+0.04
Pb—Indium-Plated Steel					+0.01	+0.01

[1]With phenothiazine

In general, the blend containing 5.0 weight percent of organophosphates was preferred for anti-wear and extreme pressure properties, and acceptable on the basis of oxidation and corrosion stability. The composition of the lubricant was, therefore, finalized to contain 5.0 weight percent of this type of additive and the necessary quantities were ordered for engine testing. Some physical properties of the finished fluid (Composition Q) are:

Viscosity, cs. at 210F. 5.30
Viscosity, cs. at —40F. 2,700
Four Point, °F. ..... <—75
Flash Point, °F. 450

VI. SERVICE TESTING

Conclusions based on data obtained from service testing of Fluids F and Q are listed as follows: (1) Composition F performed satisfactorily in the gear section of a turbo-prop engine. No corrosion problems arose. (2) It caused excessive sludge formation and corrosion in the power section of a turbo-prop engine. (3) Composition Q operated satisfactorily in the power section of a turbo-prop engine. (4) Performance of this fluid in a gear section was borderline in one case and acceptable in another instance. (5) Used samples of Fluid Q showed no oxidative deterioration or decrease in oxidation and corrosion stability after a 237 hour test. (6) A 7.1 per cent viscosity decrease of the Composition Q sample removed from the gear box is indicative of good shear stability of the fluid, when subjected to the severe shearing action of highly loaded gears.

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This work was performed under a joint Air Force-Navy contract with the Pennsylvania State College. Unless otherwise indicated, all data herein are the results of investigations conducted at this college in its Petroleum Refining Laboratory under the direction of Dr. M. R. Fenske. The author expresses his appreciation to that Laboratory and to those who assisted in the preparation of the manuscript.

(Hutt, Continued from page 182)

OIL SUPPLY

If the temperature in the contact is indeed the controlling factor in lubrication failure then cooling efficiency must be of special importance and it might be supposed that the rate at which oil is supplied to the gears exercises a critical influence on the load they will carry without scoring. There is some evidence that this is so notwithstanding that in a series of experiments at Thornton, increasing eightfold the rate of supply of a straight mineral oil to a pair of 3¼-inch centres gears of 5DP rotating at about 4000 rpm permitted on the average no significant increase in the maximum load which could be carried without scoring, nor did increasing the velocity of the jet of oil from 52 to 1880 feet per minute for a constant flow rate of ½ imp. pint per minute. Apparently the lowest rate of flow tried in these experiments, namely ¼ pint per minute, was more than enough to effect all the cooling that was possible in the circumstances. On the other hand other experiments with a machine in which two 1½-inch diameter steel bearing-balls were rolled on each other with a measure of sliding between their contacting surfaces, as in gear teeth, showed that the influence of oil-flow rate on the scoring load of the rubbing surfaces was practically linear between the limits of zero and 1 imp. pint per minute, an overall increase in load-carrying capacity of nearly forty percent being obtained over this range. Probably flow rate is important only when stinted, and if oil is supplied in the copious flood which is usual with high-duty gears the precise volume may have little influence on load-carrying capacity. High-speed photography has revealed[16] that oil supplied at the rate of ½ imp. pint per minute to the 3¼-inch centres gears mentioned above continues to stream off the faces of the teeth during the remainder of their passage—at 2000 rpm—between successive immersions in the jet of oil. No trouble traceable to insufficiency of the oil supply has been encountered at Thornton in trials with gears running at speeds up to 15,000 rpm (pitch-line velocity 19,000 ft. per min.) so that a former fear that the teeth of ultra high-speed gears such as those of the propeller-turbine aircraft engine might be stripped of their oil by centrifugal force seems to have been unfounded. It appears to make no difference whether the oil is directed on to the teeth as they go into or come out of mesh, though it has been suggested[17] that the widespread practice of supplying oil to the teeth from the ingoing side adds materially to the working loads, besides possibly carrying in abrasive dirt entrained in the oil stream.

CAN GEAR PERFORMANCE BE PREDICTED?

Research workers in the field of gear lubrication are aware that a great deal of practical investigation is in progress at the present time, ranging from very extensive tests with laboratory gear rigs by numerous interested bodies to the full-scale trials by the United States Navy[18], and it is to be hoped that more will eventually emerge from all this work than a mere series of disconnected observations on the behaviour of gears of various kinds and sizes in various specific situations. The ultimate aim of all experimentation with gears and gear rigs should be to enable the performance of working gears in machinery of all kinds to be reliably forecast on sound theoretical grounds and lubrication requirements to be accurately calculated. A method of calculating, on an empirical basis, the scoring resistance of spur and helical gears has already been proposed[17] and another step recently taken in this direction[12] has led to the successful prediction of scoring loads with straight-mineral oils on the well-known I.A.E. 3¼-inch centres Gear Rig. The adaption of Blok's expression for the temperature flash at the contact between sliding surfaces to the special case of

mating gear teeth yields a simple, experimentally verifiable, relationship between scoring load, W, and rotational speed, N, of the pinion, which can be combined with an empirical relationship between scoring load and nominal viscosity, Z, established on this machine, to give the equation:

$$W = (aZ^{1/3} - bT)/N^{2/3}$$

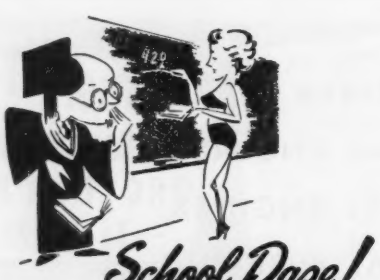
where T is the bulk oil temperature and *a* and *b* are constants for this machine.

A hopeful first step towards the ultimate goal of a general formula that will enable the lubrication requirements of gears to be predicted is to equate the calculated temperature flash in the tooth contact to a hypothetical critical temperature for failure, characteristic of a given oil and combination of rubbing surfaces and calculable from the results of tests in a simple laboratory apparatus. Eventually it might prove possible to relate this temperature to physico-chemical properties of the oil and rubbing surfaces. Reliable knowledge of the coefficient of friction between gear teeth and the manner in which it may vary with changes in the ratio of sliding to rolling, is probably an essential requirement in the development of a theoretically sound formula for predicting the maximum transmissible horsepower of gears, and one that has yet to be met, though investigations to that end are proceeding.

Among the difficulties associated with the development of such a formula are the rarity of reliable data concerning gear failures in service, against which the validity of the formula could be checked, and the prohibitively high cost of accumulating in any one laboratory substitute data of sufficiently wide scope to cover the whole range of practical operating conditions.

CONCLUSION

Though the practical problem of selecting the right lubricant for a specific application can usually be solved by reference to the immense body of practical experience that has been accumulated in this field, the final choice is essentially an empirical one and the theoretical justification for it not always clear. However, the progress achieved in recent years encourages the belief that a full solution of the important problem of predicting the performance of gears of all kinds is not indefinitely remote.



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COMMENTARY

by S. S. Sorem & A. G. Cattaneo

Mr. Hutt and his co-workers have tackled one of the most challenging engineering problems in their efforts toward finding a sound theoretical explanation of gear lubricant performance. Their work shows the direction and order of magnitude of the effects of speed, viscosity and temperature, and these empirical facts should be of direct value to the gear designer. Data obtained in the writer's laboratory generally confirm, for non-reactive straight mineral oils, the score-limited performance defined by Mr. Hutt's equation.

While this equation, derived from the flash temperature concept, provides a good fit for the data, it should be realized that this has been accomplished by a rather arbitrary choice of a coefficient of friction and an assumption of a negligible contribution by hydrodynamic forces. A rather different line of reasoning which assumes a major contribution by hydrodynamic forces can also be used to explain the above-mentioned data. This is as follows:

1) The total load between two mating gear teeth is the sum of two forces, one a direct power function of the mean torque transmitted (Mr. Hutt's scoring load) and the other, a dynamic force resulting from the shock of tooth contact. This dynamic force will be dependent upon gear

speed and, in certain cases where a negative clearance exists because of the deflection of loaded gear teeth, also dependent upon transmitted load. The existence of this additional dynamic load has long been recognized by the gear designer and he has allowed for it by using Barth's equation. Since the forces to which the oil film is subjected are the same as the ones which the gear tooth bears, it would seem entirely logical to use the experience proved Barth's equation to allow for additional dynamic loads on the oil.

2) The magnitude of the integrated hydrodynamic pressure over the tooth contact area is not adequately described by the classic hydrodynamic approach based on journal bearing experience. Other factors, such as the forces necessary to "squeeze out" a lubricant film subject to the high rate of tooth approach, and the changes in film boundaries resulting from gear tooth deflection, cause an increase in hydrodynamic pressure which is not accounted for in the classical equation based on steady flow conditions. Recent work by Gatcombe[1] and Cameron[2] tends to confirm this point of view.

If the increase of tooth load with speed is greater than the increase of hydrodynamic pressure with speed this would explain the apparent anomaly of lower permissible transmitted torques at higher speeds which Mr. Hutt reports as evidence against the hydrodynamic theory.

With this hypothesis in mind, an empirical equation was set up by Borsoff, et al[3] which expresses the score-limited horsepower of a given gear set as a function of oil viscosity and gear speed, for non-reactive mineral oils, where only hydrodynamic forces separate the gear teeth. Temperature enters this relationship only indirectly as a factor affecting oil viscosity. This equation, as would be expected, bears a great resemblance in form to Bath's modification of the Lewis gear tooth strength equation. It gives a load-speed relationship very close to the $N^{2}/_{3}$ relationship presented by Mr. Hutt.

The temperature factor may introduce considerable confusion into any attempt to rationalize gear lubricant performance if lubricants having any appreciable chemical reactivity toward the gear tooth surfaces are used. Whereas non-reactive mineral oils suffer loss in load carrying capacity with an increase in temperature, as would be predicted by either Mr. Hutt's equation or that presented by Borsoff, the presence of small quantities of reactive components, such as the sulfur compounds found in some conventionally refined mineral oils, may entirely alter this relationship, since such components will become increasingly reactive with increasing temperature.

Mr. Hutt's paper has done a great deal to stimulate thinking on the subject of gear lubrication. Only by such work on the various lubrication theories can we hope to arrive at reliable quantitative relationships which the gear designer so urgently needs.

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AUTHOR'S CLOSURE

There is enough meat in this stimulating contribution to furnish a very substantial banquet for the protagonists of hydrodynamic versus boundary lubrication, and it is scarcely possible within the short space available to do more than pick one or two bones with the providers of it. Briefly then, is it quite just to imply, as the authors do, that the success of the simple formula for predicting scoring load, derived by Lane and Hughes (Ref. 12) from flash temperature theory, depends upon an arbitrary choice of a coefficient of friction? True, the coefficient of friction was assumed constant with speed, in the absence of exact knowledge of its behavior and this is admittedly a weakness, though current investigations, referred to in the text, may eventually remedy it. First indications are that the range of variation is small. The suggestion that the shock of tooth contact at higher speeds may, by adding dynamic load, reduce the load-carrying capacity at a time when, according to the theory of hydrodynamic lubrication, it ought to be increasing, is ingenious and resourceful but overlooks the fact that the average dynamic load must always be zero (since the mean total load must correspond with the horsepower transmitted) and that other parts of the teeth must therefore be relieved of load. The practice followed at Thornton of taking the average of the scoring loads in approach and recess (when they differ, which is seldom with properly tip-relieved gears) and so obtain the load corresponding to shock-free operation, allows for this, but even so scoring load still decreases with increasing speed.

The empirical equation set up by Borsoff et al (Ref. 9) to predict gear failure represents a bold step in the right direction and scarcely deserves many of the strictures that have been passed on it by critics who have offered nothing better in its place. At the same time it must be recognized that its application involves a philosophical difficulty of interpretation which must surely militate to some extent against its permanent acceptance. Being based on a formula frankly purporting to predict tooth breakage it nevertheless incorporates factors responsible for scoring. Accordingly, when substitution of the appropriate values results in an indication of "failure," what type of failure are we to expect—tooth breakage (Lewis), or scoring (Borsoff)?

However, let it not be thought that the writer wholly condemns the approach of Borsoff et all which has just been so ably defended by Messrs. Sorem and Cattaneo. In the present state of knowledge of gear lubrication there is room for both theories and the final choice will have to be made in the light of knowledge yet to be won and on grounds of practical achievement.

(Faust, Continued from page 185)

measurements of the amount deposited from each of the six jets, there would result six equations, and each equation would contain six unknowns. By solving these six equations, it would be possible to establish a weight distribution curve for the heter-disperse aersol.

Obviously, a great deal of the detail was of necessity omitted from this discussion. However, a typical particle-size weight-distribution curve for a micro-fog lubricator is of interest and is shown in Fig. 7.

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to 2.0 microns in diameter. A lubricating aerosol having this range of particle sizes we found could be conveyed over considerable distances without danger of excessive loss or condensation within the piping system; and at the discharge point, the oil fog could be satisfactorily utilized for lubricating purposes. The method used for achieving good lubrication varies, depending upon the circumstances and the application at hand.

Generally speaking, any bearing, or similar lubricating problem, where the primary purpose is to lubricate the parts involved, and where the air is used merely as a conveyor for the oil fog, it is, of course, desirable to keep the air consumption as low as possible. For this type of problem, we recommend a micro-fog lubricator having an operating range of from 1 to 3 c.f.m. With this lubricator, and for this purpose, we recommend the use of a reclassifier at the point of application to assist in reclassifying or condensing the oil fog so that it is more readily wettable and will, therefore, provide better lubrication.

The reclassifier is a simple little fitting installed in the bearing housing and to which the oil-fog line is connected. Its purpose is to increase the particle size of the oil fog as it is passed through the reclassifier, thus rendering the fog more readily wettable. The oil still emerges from the reclassifier as a fog, but the particle size of the fog is considerably greater than it was upon entering the reclassifier.

When applying micro-fog lubricators to small air-operated tools having air consumption of approximately 3 to 14 c.f.m., it is generally not necessary to use a reclassifier. In this application, the air is used to drive the tool as well as serving as a means of conveying the lubricant. The velocities obtained in such a system are generally sufficient to cause satisfactory wetting and lubrication of the tool without the benefits of the reclassifier.

Aerosol, or oil-fog lubrication, is not the answer to all lubrication problems. However, this form of lubrication has achieved many satisfactory results and solved many heretofore difficult lubrication problems after other methods of lubrication had failed. It is convenient, automatic, and inexpensive. Frequently, considerable savings are to be obtained, these savings resulting from the reduction in maintenance costs and conservation of lubricants. For the lubrication of extremely high-speed bearings (it is considered by many to be the only form of lubrication which is acceptable and satisfactory.

COMMENTARY

by R. Q. Sharpe
Socony-Vacuum Oil Co.

Mr. Faust's paper presents a very thorough and interesting study of a method of oil application which seems destined to occupy an increasingly important position in Industry. The lubrication of mechanical parts by the introduction of oil into a gaseous stream, of course, is not new. For many years steam engine cylinders have been lubricated by supplying oil to a quill in the steam line where it is picked up and atomized by the steam for the cylinders. Good distribution and excellent lubrication result if the design and lubricant are correct. Also, heavy-duty rock drills are lubricated by a line oiler from which the oil is picked up by the air stream and carried into the mechanism. In both of these methods of lubrication it is probable that the droplet size and the rate of oil feed are much larger than commonly encountered in a fog lubricator of the type under discussion. To the best of my knowledge, no detailed study has ever been made of the degree of atomization or particle size of the oil in such applications.

Fog lubricators of the type described by Mr. Faust have been used widely for the lubrication of anti-friction bearings operating at speeds ranging from a few hundred r.p.m. to as high as 200,000 r.p.m. Excellent performance results have been secured. Not only does oil fog adequately lubricate this type of bearing but it may perform incidental benefits. The spindle of an oscillating grinder had been lubricated with a light viscosity oil fed by means of drip oilers. Under this condition some soluble oil and grit entered the bearings past the seals causing premature bearing failure. The application of an oil fog lubricator provided a slightly positive pressure within the spindle housing which prevented the entry of the soluble oil. Substantially increased bearing life resulted.

To this commentator's knowledge, no particular problem has arisen as a result of the inadequate wetting of the wearing surfaces of anti-friction bearings when lubricated with oil fog. It is not known whether the very severe churning action of the anti-friction bearings may agglomerate the minute oil particles into sizes which provide adequate wetting, or whether an oil film may result from the high impact velocities between the fog and the moving parts.

Because the oil-fog method of applying lubricants to mechanical parts provides certain advantages, considerable interest has developed in its possible application to plain bearings, gears and slides of industrial machinery. The studies reported by Mr. Faust in this paper and his paper entitled, "Wetting Characteristics of Lubricating Aerosols *Product Engineering*, July, 1951 Vol. 22, No. 7, should be of direct benefit in connection with applications of this kind. The lubrication of parts such as these by oil fog may be considered still in the experimental stage and much field work needs to be done before specific answers will be available as to the practical limitations of this means of lubrication. Undoubtedly, careful field testing and analysis will develop some correlation between the excellent work on particle size reported by Mr.. Faust and actual field performance. Such evaluations require the close cooperation of the lubricator manufacturer, the oil supplier and the user. Through the activities of these three principals, widely expanded use of oil fog for the lubrication of industrial machinery is bound to result.

I should like to compliment Mr. Faust on his Paper and the painstaking work which it reports. It is believed that basic work of this character is a very necessary and desirable step in the advancement of this method of application.

COMMENTARY

by W. E. Johns
Sundstrand Machine Tool Co.

The research program carried on by the Norgren Co. and described in the "Oil-Fog Lubrication" paper is an excellent example of the many fundamental contributions that industry is making to the engineering world today. Utilizing techniques usually associated with theoretical considerations within the physical and chemical laboratory, the program has provided an evaluation of aerosol lubrication which has practical application in everyday design problems. A comprehensive research study is often appraised only from the standpoint of the exactness of the scientific methods employed. Such an appraisal of Mr. Faust's paper would lose much of the dynamic significance of this thorough basic investigation.

In the design and application of air-operated tools, optimum lubrication of all of the specific bearing surfaces is a detailed problem. Generally speaking, it is desirable to consider the air used to operate the tool as the transfer system for lubricant and to design the air passages through the tool in such a manner as to subject all of the bearing surfaces to the air flow. In this manner, it is possible to provide lubrication continuously, during operation of the equipment, with little attention on the part of the operator. There are, however, some persistent difficulties associated with air distribution of the lubricant. Oil, carried by air into the tool, may be deposited generously upon the component parts of the governor assembly where the lubrication requirements are very negligible, or upon the surfaces within the restrictor valve chamber never to reach the main bearings of the unit. Just as serious a problem, from the application standpoint, is to have oil carried by the air into the tool, exhausted and deposited on a finished surface—a problem not uncommon in sanding and polishing operations.

Packed and sealed bearing assemblies are one answer to the lubrication problem of tool applications for finishing equipment where the toleration of oil is low; however, if the bearing is sealed, it eliminates the very positive temperature reduction of the bearing surfaces which results from exhaust air passing through the bearing. This temperature reduction, with the associated improvement of film characteristics of the lubricant, provides for increased load capacity and longer earing

life. Thus, to the designer of air operated equipment, an additional direct benefit results from the use of the air distributed oil lubrication system.

Typical bearing problems involve shaft speeds of 15,000 r.p.m., rotor and vane rubbing contact with the air motor housing at 10,000 surface feet per minute, and oscillating bearings operating under load through only a few degrees of rotation at 3000 cycles per minute. As field requirements become more demanding in the future, the design load and life limits of the present bearings must be increased. From an engineering standpoint, the improvement in performance should come from refinement in the bearing technique rather than from an increase in bearing size or cost. Provision for adequate lubrication and control of localized bearing heating will increase present bearing design limits. These considerations are particularly emphasized through the evaluation of aerosol lubrication in an air tool! With available information on the *limiting*—physical dimensions, system velocities and temperature depression range required to achieve particle size control of the aerosol, the designer may proceed toward an optimum lubrication design.

Ideally, the aerosol would enter the tool as an extremely fine particle dispersion with little or no wetting within the restrictor or governor valve chamber. Lubrication of motor vanes and motor surfaces would normally be sufficient as a result of contact wetting with the finest particle fog. From the motor chamber, the aerosol would pass through the necessary reclassication passages and be directed to the main equipment bearings. At the bearing there would be a reduced temperature, high volume, large particle size aerosol dispersion, with a terminal condition of adequate bearing surface wetting and minimum bearing surface temperature for a given design problem.

(Barnett, Continued from page 188)

The two cooperative samples now being investigated represent two widely used aircraft greases as covered by government specifications ANG-5A (high temperature grease) and ANG-25 (wide range synthetic grease).

It is the purpose of the Laboratory Panel to achieve correlation with field performance by use of the simplest design possible. If it is not possible to do this with the Fafnir-type tester, then it will be necessary to construct a more universal type of tester which will allow the testing of ball, roller, or needle bearings under conditions of radial and thrust load. Thought has been given to the design of such a tester by a subpanel of the main Laboratory Panel.

ASTM ACTIVITY: The American Society for Testing Materials held a symposium on fretting corrosion during the annual June meeting in 1952. This symposium was sponsored by ASTM Technical Committee G. (See reference[14] for schedule of papers.)

MITIGATION OF FRETTING CORROSION

The foregoing discussion dealt largely with the cause of fretting corrosion and how to detect the occurrence of this phenomenon. To summarize what has been found through the examination of conditions effecting fretting, the following is given as a condensed guide toward the minimization of fretting.

1. Use as fluid a lubricant for actual bearings as can be retained. This will go a long way towards keeping surfaces from rubbing themselves to the point of cleanliness where molecular attraction can occur.
2. Modify the surface by vapor blasting or with a bonded coating of MoS_2 if feasible. Sacrificial lead coatings, and chromium or copper plating in cases such as bearing shafts or test machine arbors, are effective in some cases.
3. Minimize vibration.
4. In the case of oscillating antifriction bearings, reduce the load and seek to have the rotation increased to at least 180 degrees to bring fresh lubricant into the areas of contact.
5. Use surfaces as dissimilar as possible regarding surface finish and hardness.

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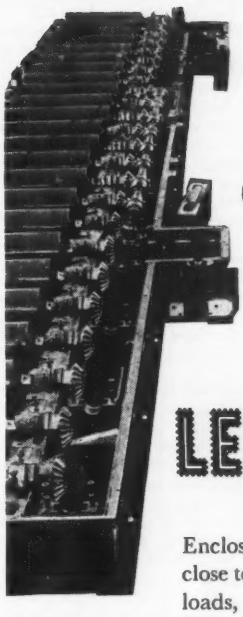

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The Author wishes to acknowledge the valuable contributions of G. R. Furman of Beacon Laboratories in developing the reasoning presented in the section of this article dealing with the detection of fretting corrosion in used bearings and machine parts.

(Lube Lines, Continued from page 197)

cart axles to grinding-wheel spindles, one of man's most persistent problems has centered around the reduction and control of friction.

Early machinery consisted of spindle pulleys, windlasses, and carts and wagons equipped with wheels and axles. These mechanisms were made of wood. The bearings were rough, and if lubricated at all, were in all probability packed with fat taken from the bodies of animals. The chariot found in the tomb of Yuaa and Thuiu, for example, from about 1400 B.C. still had some of the original lubricant on the axle. This was analyzed by the official chemist of the Cairo museum, who found that the lubricant was sticky and slightly greasy. It contained road dirt such as quartz sand, compounds of aluminum, iron, and lime. It had a melting point of 121 degrees Fahrenheit which would have proved suitable for axle lubrication in such a warm country.

According to Pliny (A.D. 23-79) there were available at that time and in use for various purposes, oils from about the same number and kind of seeds and plants as we have at present. Some petroleum was also available along with fats and oils from animals. Primitive forms of machinery were naturally lubricated with occasional applications of whatever lubricant was at hand. For many centuries after the Christian era these conditions prevailed.

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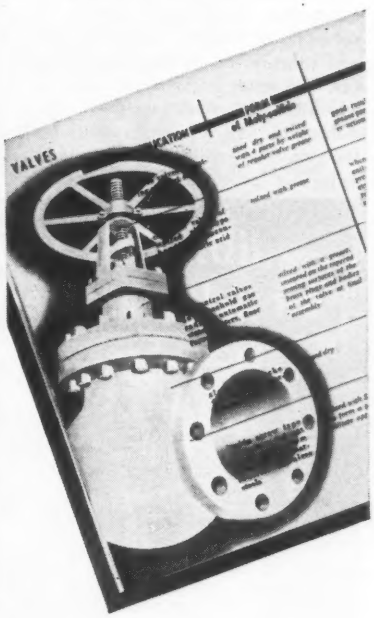

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(LS, Continued from page 189)

sult in disassociation of water into its oxygen and hydrogen molecules with attendant difficulties in curbing the fire.

Plastics, conversely, are almost always machined with water base fluids or emulsions since in the case of both the thermoplastic and thermosetting types, cooling is the predominant requirement. Such cooling is essential to prevent dimensional distortion and softening of the thermoplastic materials and charring of the thermosetting plastics. The latter frequently contain fillers which may be either beneficial or detrimental to tool sharpness and, hence, frictional heat build up. Graphite fillers help, but asbestos, fibre, paper, and rag fillers tend to dull tools quickly.

Mixing of soluble oils with water for use presents many common problems. Good cold water mixing can be controlled by the oil manufacturer in formulation but hard water (up to 700 ppm) can be compensated for in the plant by judicious use of water softeners. The common rule with materials like the polyphosphate softeners is to use about 1.5 oz. per grain hardness (1 grain equals 17 ppm) per 100 gallons of water.

Metal drawing usually entails consideration of the field of boundary lubrication, since high unit pressures, high spot temperatures, and relatively low sliding velocities prevail. Most problems in drawing lubrication are considered to be in the zone of boundary friction. Hence, lubricants must be so formulated as to be effective under these conditions, i.e., high unit pressures, low sliding velocities, and development of high spot temperatures dependent on relative surface conditions. The last factor is most important and, hence, pertinent to proper selection and use of lubricants.

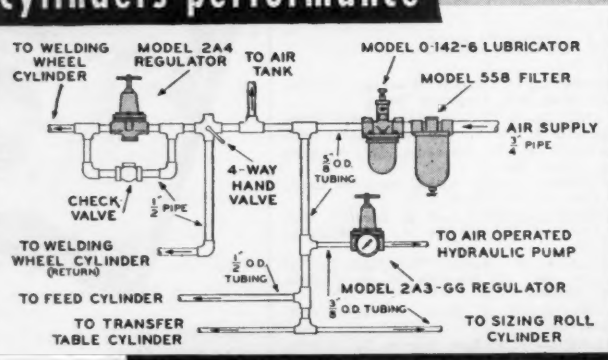
There are three general classes of material suitable in boundary lubrication, as follows: 1. Antifriction agents and polar compounds—typical are free fatty acids and fatty oils which function by physical adsorption at the metallic interface. Wear occurs by shear through the peaks of the asperities on the microscopically rough metal surface, 2. Antiwear agents or "polishing" compounds—typical is tricresylphosphate. These have a mild chemical action on the metallic surface and are more adherent. By "polishing" action, metallic peaks wear off to refill adjacent "valleys" in metal surface and present smoother surface for subsequent adsorption of polar compounds present in lubricant, thus additionally reducing friction, 3. E.P. (extreme-pressure) agents having strong chemical reactivity at metal surface—typical are sulfur and chlorine compounds to form metal sulfide and chloride films having worked antiseizure properties to prevent metal pick-up and welding. This is because these films continually "repair" themselves at points of high spot temperature where incipient seizure may occur. The high spot temperatures release additional active chemical from the lubricant to form a renewed chemical film. These films have lower shear strength than the parent metal and thus facilitate sliding and low friction relation between surfaces.

(CL, Continued from page 19)

axial groove on the unloaded side, or a circumferential groove may be affected by two factors. One results from the oil-fed pressure, and the other from the hydrodynamic-film pressure supporting the load.

TECHNICAL DATA DIGEST (CENTRAL AIR DOCUMENTS OFFICE), Vol. 17, No. 3, March, 1952, The Development of a Self-Lubricating Fuel, F. Reynaud. The search for a self-lubricating fuel for internal combustion engines has prompted a study of a series of hydrocarbons to determine compatibility between the thermodynamic and lubricating property of a given fuel. In the case of the Diesel engine, the problem appears to have found a certain solution in the form of vegetable oil fuels, e.g., castor oil. Among the synthetic compounds investigated, hexadecycylo-hexylbenzene fulfilled the requirements of self-lubricating Diesel fuel to a satisfactory degree. In the case of the Otto engine, cyclohexene and certain aliphatic olefines were found to fulfill requirements for self-lubricating fuel. The self-lubricating properties of the latter group may be further increased by hydrogenation of the end product.

NORGREN improves air cylinders performance



Norgren Oil Fog Lubrication of Cylinders helps National Welder attain 1000-per-hour Output

PLANT REPORT

NATIONAL ELECTRIC WELDING MACHINES CO.

PROBLEM: To provide positive, trouble-free lubrication of 4 air cylinders and one air-operated hydraulic pump for a special 200 KVA Welder which automatically roll-forms, sizes, feeds and mash-seam welds metal containers up to 25" in diameter.

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A Method for Evaluating the Performance of Aviation Lubricating Oils In Service, C. R. Major and W. A. Snell. The rating system evolved has facilitated the collection of oil performance data from the field and has made possible detailed comparisons of the performances of various oils in different engine types operating under a variety of conditions. The outstanding feature of the basic rating system is its flexibility. A simplified version of the system is presented.

(SN, Continued from page 19)

ucts, covering the more interesting aspects of the Inspection Service, its purpose, and the manner in which inspection is applied to actual products.

June 1952 meeting—Dr. B. W. Hotten, California Research Corp., presented an address entitled Fundamental Knowledge of Lubricating Grease Structure, discussing the composition and functional requirements of greases, the theories of the physical structure of greases, and the evidence in favor of the microcrystalline paste theory, with the variation of fiber structure with thickener composition shown in electron micrographs. (Submitted by P. M. Ruedrich, Sec'y-Treasurer.)

PITTSBURGH

April 1952 meeting—Laboratory tour of the National Tube Co. Lubrication Laboratory with demonstrations and explanations of such tests as Ball E. P., 4 Ball Wear tester, Timken, Norma-Hoffman Oxidation, Indiana Oxidation, Motormatic Grease Worker, Shell Roller test, Micro-cone Penetration, Taper Disc Penetration, Phalex, Wheel Bearing, and ASTM Turbine Oil Test D-443. (Submitted by F. R. Ross, Sec'y-Treasurer.)

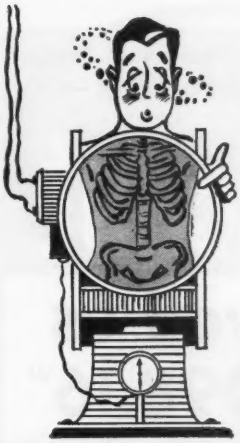
ST. LOUIS

April 1952 meeting—Metalworking & Forming Compounds, by E. L. H. Bastian, Shell Oil Co. (See Lubrication Summarized). (Submitted by M. J. Croghan, Jr., Sec'y.)

YOUNGSTOWN

May 1952 meeting—Following the annual election of officers (See Directory), a Stump the Experts panel was held with panelists O. L. Maag, Timken Roller Bearing Co., E. M. Kipp, Aluminum Co. of America, and C. A. Bailey, National Tube Div., U. S. Steel Corp. (Submitted by R. S. Scheidemantel, Sec'y.)

NOTICE: TWO NEW MICHIGAN SECTIONS BEING ORGANIZED. A section to service the areas of Grand Rapids and Muskegon is being organized rapidly. Another section, which will include southwestern Michigan, is being organized with headquarters in Kalamazoo. This section will include such industrial areas as St. Joseph-Benton Harbor, Niles, Battle Creek, and Kala-



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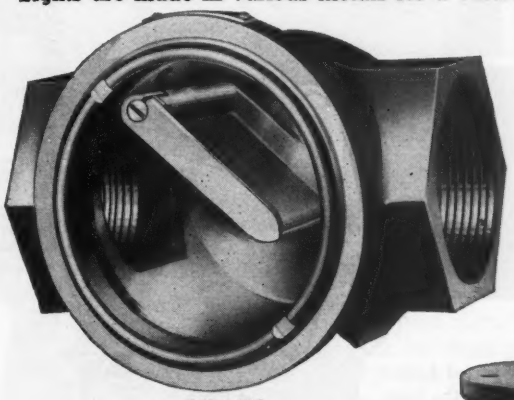

FIG. 811

This vane-type Bowser Indicator is spring-actuated, thus providing an indication of the quantity flowing in the line.

FIG. 811

FIG. 54A

This Bowser Flow Sight is recommended for use on gravity lines where the flow is vertically downward.

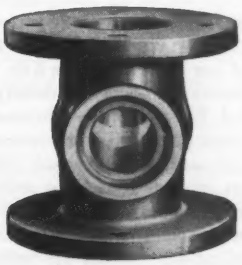

FIG. 54A

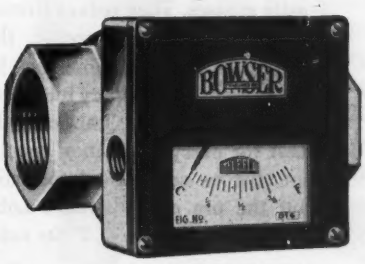

FIG. 816

The Figure 816 Bowser Teleflo Indicator is equipped to operate a gong or to stop pump motor if liquid flow stops.

Consult with the Bowser engineer nearest you.

FIG. 816

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mazoo, Michigan. All interested parties should contact their organizer: D. W. Benner, Lincoln Engineering Co., 3482 Davison Road, Lapeer, Michigan. (Mr. Benner has just completed the organization of the Saginaw Valley Section.)

(PA, Continued from page 193)

a hydrocarbon in the lubricating oil boiling range, 0.5% to 2.0% by weight tall oil, 0.5% to 2.0% by weight of a polyhydroxy alcohol, 0.3% to 1% by weight of an oil soluble corrosion inhibitor, 0.05% to 0.2% by weight of a fatty acid, and a solid having lubricating properties selected from the class consisting of talc and mica in a ratio in the range between 1:2 and 2:1 to said base oil.

GREASE COMPOSITION, Patent #2,599,683, S. T. Abrams and F. H. Stross, assignors to Shell Development Co. A grease composition comprising a lubricating oil, 5 to 40% by weight of said composition of a substantially anhydrous inorganic gel of an amphoteric metal, said gel retaining in the composition the gel structure substantially as originally formed, and 2 to 20% by weight of said gel of a lipophilic acid containing at least one hydrocarbon radical having at least 10 carbon atoms and being selected from the group consisting of phosphinic acids, aliphatic dicarboxylic acids, amino fatty acids, sulfonic acids, and naphthenic acids.

LUBRICATING COMPOSITION CONTAINING THE REACTION PRODUCT OF BIURET AND ALIPHATIC ESTERS OF HYDROXY ACIDS, Patent #2,599,736, D. E. Adelson and R. G. Larsen, assignors to Shell Development Co. A lubricating composition comprising a major amount of a lubricating oil and a minor amount sufficient to inhibit wear and oxidation of a reaction product of a biuret and aliphatic esters of hydroxy acids, said reaction product being formed by heating the reactants in the ratio of about 1:1 to 6:1 mols, respectively, and at a temperature between 100 and 250 C. for a period of 30-100 hours.

EXTREME PRESSURE LUBRICANT, Patent #2,599,761, D. Harman and R. E. Thorpe, assignors to Shell Development Co. A mineral lubricating oil composition comprising a mineral lubricating oil and a minor amount, sufficient to impart extreme pressure properties to said mineral oil, of a reaction product of tributyl phosphite with dibutyl trichloromethane phosphonate, said materials being reacted in about equimolar proportions at a temperature of from about 100 C. to 200 C.

LUBRICATING COMPOSITIONS, Patent #2,599,794, W. C. Webber, assignor to Shell Development Co. A lubricating composition comprising a mineral lubricating oil having incorporated therein in an amount sufficient to impart extreme pressure properties thereto nitro-1, 3-benzodiozane containing from one to two trichloromethyl radicals directly attached to the dioxane ring, said nitro group being attached directly to the 6-position of the benzodioxane.

LUBRICATING COMPOSITION, Patent #2,599,803, S. A. Ballard, R. C. Morris, and J. L. Van Winkle, assignors to Shell Development Co. A stable lubricating composition comprising as the major lubricating constituent thereof a liquid saturated aliphatic acid diester of a polyalkylene glycol, the alkylene units of said glycol having from 2 to 20 carbon atoms, the molecular weight of said glycol being from about 400 to about 1600, and said acid containing from 2 to 20 carbon atoms; and 1-10% of a linear polymer of an acrylic acid ester selected from the group consisting of acrylic esters and methacrylic acid esters, having an average molecular weight within the range 5,000 to 25,000.

SILOXANE LUBRICANTS, Patent #2,599,917, M. C. Hommel, assignor to Dow Corning Corp A lubricant composed of a halogenated arylpolysiloxane fluid, from 2% to 10% by weight, based upon the weight of the mixture of a compound selected from the group consisting of chlorinated biphenyls containing from 48% to 62% by weight chlorine and chlornaphthaxanthate containing 31% chlorine and 11% sulfur, and from 0 to 2% by weight based upon the weight of the mixture of a sulfide selected from the group consisting of benzyl bisulfide and 2, benzylthiacyl, N,N—diethylthiocarbamyl sulfide, said halogenated arylpolysiloxane having a degree of substitution greater than 2 and less than 3 organic radicals per silicon atom, said siloxane containing halogenated aryl radicals selected from the group consisting of halogenated phenyl and halogenated xenyl radicals having substituted therein from 1 to 7, inclusive, halogen atoms selected from the group consisting of chlorine and bromine, the remaining organic radicals in said siloxane being selected from the group consisting of methyl and phenyl radicals in which siloxane the halogenated aryl radicals are present in amount so that the ratio of halogen atoms to silicon atoms is from 0.05 to 3 and in which siloxane at least 37% of the total number of organic radicals are methyl radicals.

LUBRICANT CONTAINING SOAP OF PHOSPHATED HYDROXY FATTY ACID OR GLYCERIDE, Patent #2,600,058, E. C. Knowles, O. P. Puryear, and G. W. Eckert, assignors to The Texas Co. A lubricating grease comprising an oleaginous liquid lubricating base containing in excess of 5% and up to 45% by weight based on the grease of a metal soap of a phosphated soap-forming material selected from the group consisting of a phosphated soap-forming hydroxy fatty acid and a phosphated soap-forming hydroxy fatty acid glyceride sufficient to thicken said lubricating base to a gel-like consistency.

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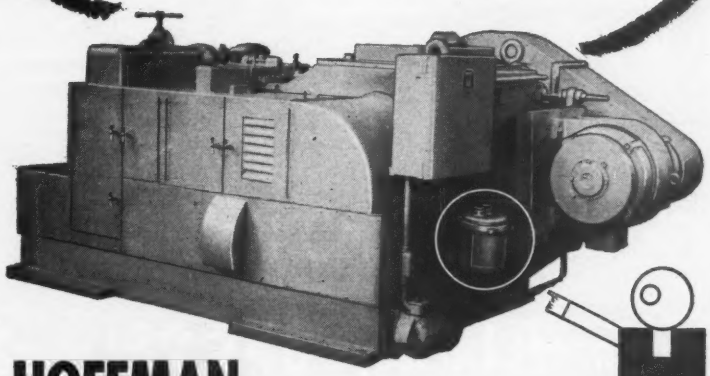

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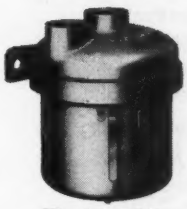

The I-6-15D

The I-4-15D

The I-6-90D

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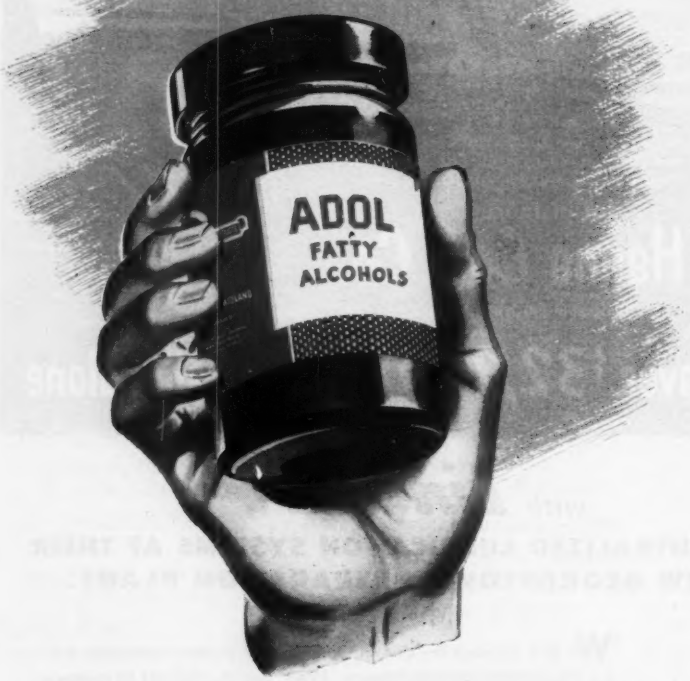

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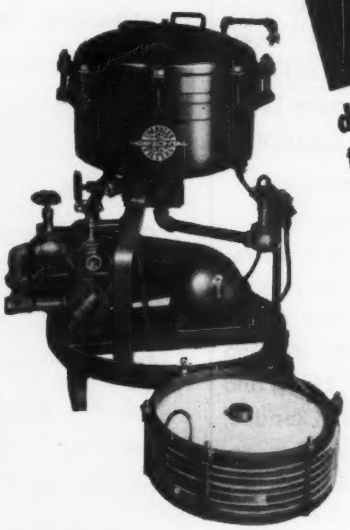

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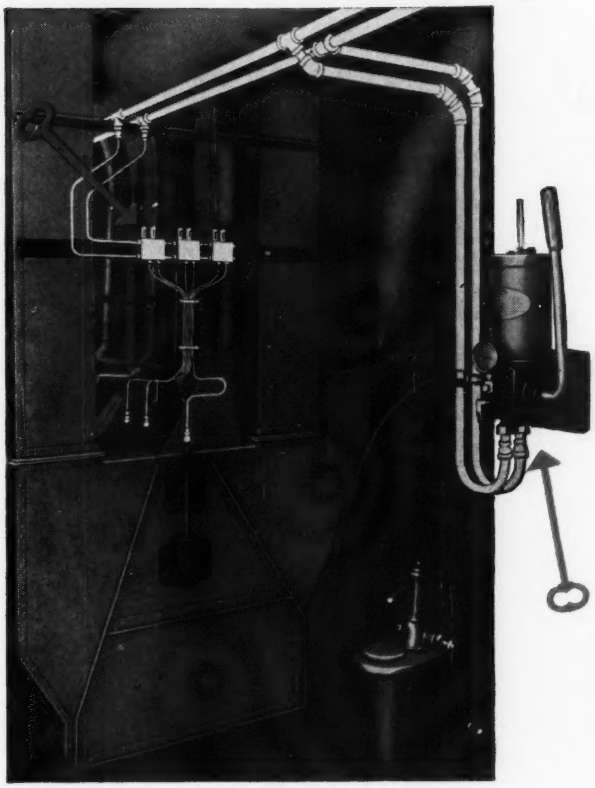

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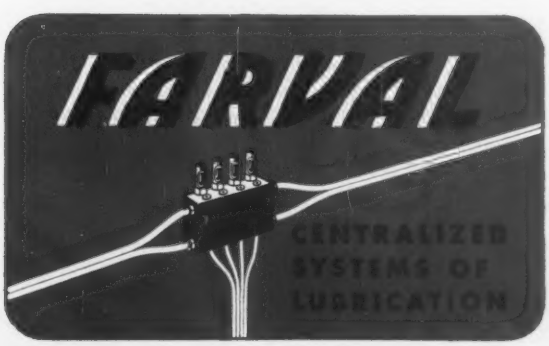

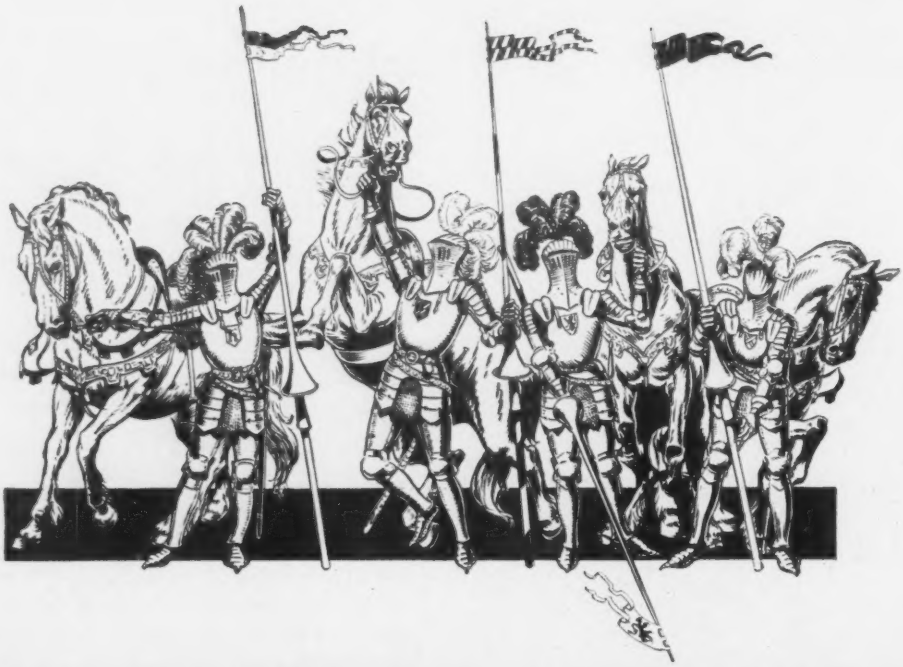

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